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UNITED STATES AIR FORCE

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AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

AFIT/GAE/AA/81D-6

INVESTIGATION OF AN IMPROVED STRUCTURAL MODEL FOR DAMAGED T-38 HORIZONTAL STABILIZER FLUTTER ANALYSIS USING NASTRAN

THESIS

AFIT/GAE/AA/81D-6

Lex C. Dodge
Capt USAF

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INVESTIGATION OF AN IMPROVED STRUCTURAL MODEL FOR DAMAGED T-38 HORIZONTAL STABILIZER FLUTTER ANALYSIS USING NASTRAN

THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

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Lex C. Dodge, B.S.E.M.

Captain USAF

Graduate Aeronautical Engineering

December 1981

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Preface

I thank my thesis advisor, Captain Hugh C. Briggs for his patience and open mind to my different methods of analysis and allowing me the freedom to pursue both our hypotheses.

Thanks goes to Dr. Venkayya and Mrs. Victoria Tischler for their special interest in my NASTRAN problems. I also thank Major Gene Hemmig and Mr. Dale Cooley for their technical assistance.

I extend special thanks to my wife and typist Laurie for her assistance in the completion of the thesis.

Lex C. Dodge

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Abstract

This thesis investigates tuning a finite element model and applying the procedures to the T-38 horizontal stabilizer for use on NASTRAN. The T-38 stabilizer model is to be used in a subsequent flutter analysis.

Static and dynamic analysis has shown the model to have inadequate bending and torsional stiffness. The model was tuned in the frequency domain with free-free boundary conditions. The tuned frequencies and mode shapes show good correlation to the measured values. The finite element model was shown to not contain variables that significantly influence the torsion modes frequencies more than the bending frequencies.

Eigenvalue analysis of the tuned model with aircraft installed boundary conditions produced good results for all but the first torsion frequency. This frequency was tuned by increasing the model's control system stiffness. This tuned model produces good frequencies and mode shapes. Additional investigation is needed to compare the dynamic model corrections to the static model corrections found by Jack Sawdy, AFIT/GAE/AA/81D-27.

INVESTIGATION OF AN IMPROVED STRUCTURAL MODEL FOR DAMAGED T-38 HORIZONTAL STABILIZER FLUTTER ANALYSIS USING NASTRAN

I. Introduction

Background

San Antonio Air Logistics Center (SAALC) has been interested in having a more advanced method for performing flutter analysis on the T-38's horizontal stabilizer. Using the current repair criteria for the horizontal stabilizer 3 of 102 stabilizers removed from service in a recent two year period were found to be within repair limits. SAALC is currently experiencing difficulty in obtaining sufficient quantities of spare stabilizers. This situation is beginning to impact mission performance. It is expected that using new structural and aerodynamic techniques with NASTRAN flutter analysis will yield a less conservative answer than the current flutter speed predicting techniques. SAALC initiated developement of the finite element structural model and investigation of the use of the Doublet Lattice Method. The investigation has been continued by Air Force Institute of Technology (AFIT) thesis students.

Previous Investigations

John O. Lassiter, AFIT/GAE/AA/80M-2 began the investigation. Lassiter built the Bulk Data Generator which creates the stabilizer structural model for NASTRAN. Lassiter started the aero model investigation.

Roger K. Thomson, AFIT/GAE/AA/80D-21 pursued the investigation and problem areas identified by Lassiter. Thomson built the aero model and checked it against preliminary steady windtunnel data. He performed an experiment to measure the free-free modes and frequencies of a T-38 horizontal stabilizer.

Lassiter found that a Series 2 and Series 3 stabilizer existed. Their major differences can be seen in Fig 1 and Fig 2. NAI-57-59 (Ref 1:V) stated that the difference in section properties and stiffness between the two stabilizers was negligible. For this reason Northop repeated few tests on the Series 3 stabilizer. The Series 3 is the stabilizer in use. In order to gain test data on a Series 3 stabilizer to check the finite element model Thomson conducted a modal survey of the stabilizer. The measured frequencies were higher than the frequencies produced using NASTRAN, however the mode shapes compared quite well. These results were consistent with the static analysis done by Lassiter using NASTRAN. The model needs tuning to correct the static deflection errors and align the frequencies.

Objective of Tuning the Model

The model will be used to generate the frequencies and mode shapes for use in flutter analysis. The flutter analysis requires the model's frequencies and mode shapes to be accurate. The current flutter analysis uses Strip Theory with an elastic axis structural model. This analysis technique does not include chordwise deformation. The Doublet Lattice Method in the analysis method being developed includes chordwise deformation at discrete points along the chord, instead of averaging the deformation into a pitch and plunge of the

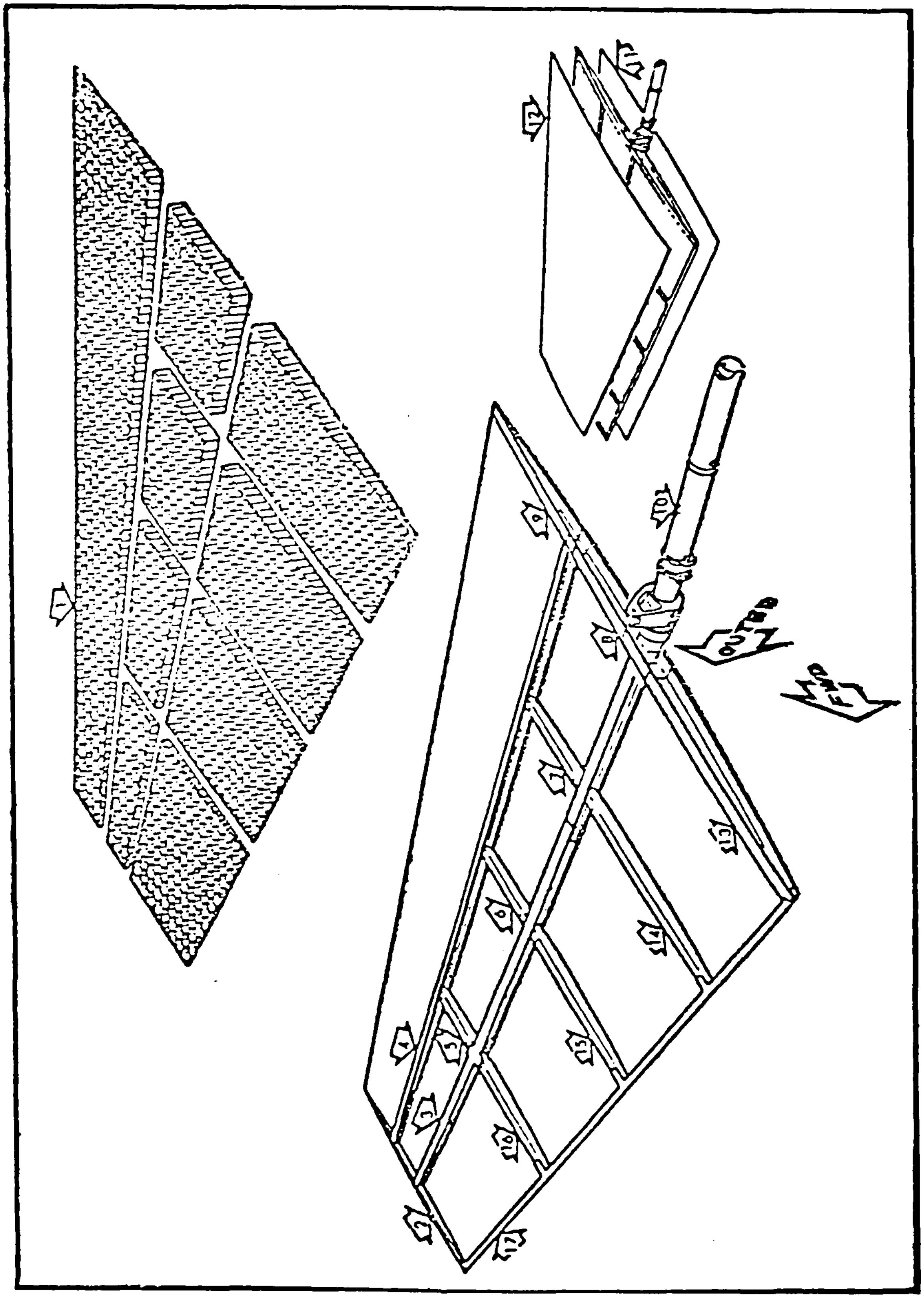


Figure 1. Series 2 Stabilizer
(Ref 6)

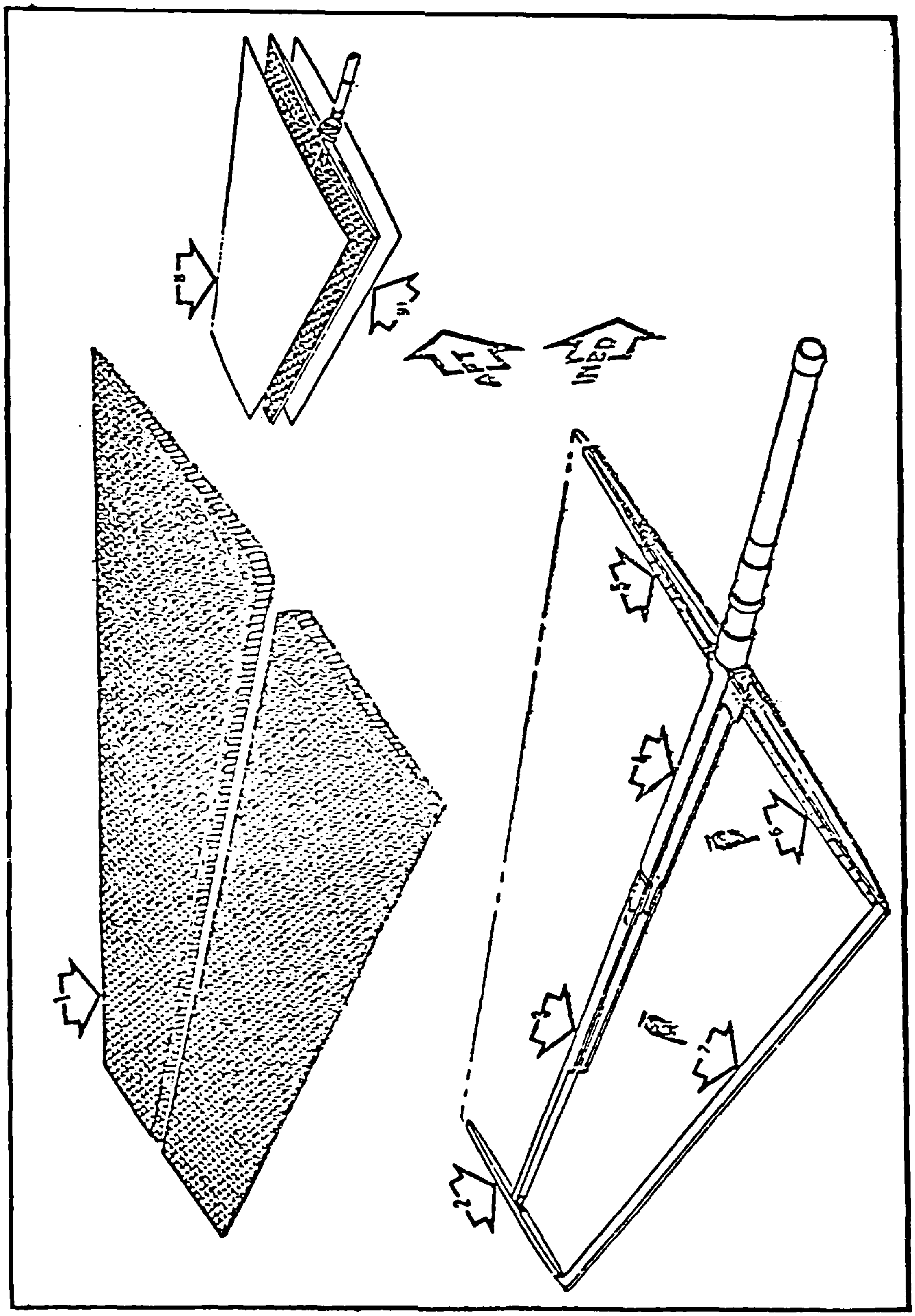


Figure 2. Series 3 Stabilizer
(Ref 6)

chord like strip theory. Therefore the mode shapes become more important in the Doublet Lattice technique.

General Approach to the Problem

The general process of tuning a model was investigated. The tuning principles found were then applied to the T-38 horizontal stabilizer model to choose the proper parameters to correct the model's frequencies. Sensitivity of the model's frequencies were checked under free-free boundary conditions. The model's frequencies were tuned to Thomson's measured frequencies. The tuned model's frequencies and mode shapes were then recalculated under installed boundary conditions. These frequencies and mode shapes were verified with ground vibration data.

II. General Approach to Model Tuning

Introduction

Most numerical models require tuning so that the model will produce the same characteristics as the real structure. This is true for static and dynamic analysis. Finite element models are built of a discrete number of pieces or elements and these elements must be of a simplistic nature that will lend themselves to numerical analysis. Therefore the model may not contain all the complexity or behavior of the real structure. The structure's desired characteristics must be simulated by the model. This simulation may be obtained by altering parameters in the model. The need for the simulation is what makes model tuning so important. This investigation will consider tuning of a model to meet measured frequencies and mode shapes.

Model Classification

The approach used in tuning a model is dependent on the type of model being tuned. Three large classes of models exist which are distinguished by their dominant structural elements. The three classes are lifting surfaces composed of multiple spars and/or ribs, lifting surfaces with mostly honeycomb filler between the skins, and body cells of circular nature with longitudinal and circumferential stiffeners. These are herein referred to as class 1, 2, and 3 models respectively.

The torsion and bending stiffness of the lifting surfaces are typically dominated by one type of element. The class 1 model stiffnesses are dominated by the beams modeling the spars and ribs. The variables in this class are the properties of the beams. The beam properties can be expected to have a much greater affect on the frequencies than the plate properties. The class 2 model stiffnesses on the other hand are dominated by the elements modeling the skin and core. The plate properties modeling the skin and core should be used in tuning a class 2 model. The non-dominant element's properties affect the frequencies and mode shapes; however, the model's sensitivity to these parameters is much less.

Each of the lifting surface models can be further divided by the method which attaches the surface to another structural section. An example is the interface between a wing and fuselage. The wing is connected to the fuselage by multiple spars and the skin. Another example would be a horizontal stabilator that is connected to the fuselage by a single member (torque tube) with no other structural interface. The wing will act like a cantilevered plate while the stabilator will act like a pin-pin beam with a lumped mass and an inertia disk attached to the beam.

The class 3 model does not have a single dominant element to resist both torsion and bending. The bending stiffness is controlled by the longitudinal beams and the bending inertia of the cell's skin. The torsion stiffness of the structure is dominated by the cell formed by the skin. If the skin is modeled with a 2-dimensional set of finite element plates then the effect of having a torsion cell will not be present. The circumferential stiffeners are the dominant element for a pressurized cell.

Parameters in Model Tuning

The parameters in tuning a model are altered to compensate for the model's inability to simulate the structure's behavior. Element properties of the model must be changed so that it will model an irregular cross sectional shape, composite structure or cell structure. Properties must also be changed so that one or two dimensional models will simulate two and three dimensional structures. The discretization of mass in finite elements may not represent the structure's mass distribution affect. The changes above can be made an element by element or across the whole structure affecting all elements.

One of the most common models used is a rectangular bending element representing an irregular cross sectional member such as a Z-section, I-beam, C-channel, etc. The properties for the rectangle are derived by equating the displacements of the two sections under equal loads and solving for moments of inertia and area. When a solid section is used to model a hollow-closed section the effect is more dramatic. A model of a circular tube with equal cross sectional area will have equal axial stiffness, but the hollow section will be approximately 550 times as stiff in torsion (Ref 2). Therefore all important displacements must be considered at the same time. This may necessitate changing material properties such as the shear modulus and modulus of elasticity as well as, or instead of, cross sectional properties. These considerations apply mostly to the class 1 and class 3 models due to the dominance of beam elements in these models.

The modeling of a 3-D or 2-D structure with a 2-D or 1-D model creates special tuning problems. This becomes very evident in the modeling of composite structures and modeling of torsion cells with finite element plates. These two structures are very common in aircraft. The composite structures commonly used are honeycomb covered by a skin of metal or the newer composite fiber type structures. Modeling of the composite structure is simplified with the use of orthotropic plate elements. These elements have independent properties in each direction that can be changed in the equivalent displacement tuning procedure described earlier. Independent directional properties will not exist for the isotropic plate element. The use of inertias and area must be relied upon for tuning parameters. Torsion cells are formed by honeycomb composites and by structures formed by ribs and spars covered by a skin. The torsion cell model will not contain shear flow effects when plate elements are used. The shear flow can be accounted for by changing the shear modulus or the thickness of the plate (App A). These parameters can change the bending and axial stiffness of the model. All important displacements must be solved simultaneously. These tuning parameters are most effective on class 2 and class 3 models.

Mass can be used to change the model's frequencies and mode shapes. Changes of mass can be accomplished by changing the density of the material (structural mass) or distributed mass (non-structural mass). Changes in mass can be applied to all three model classes.

The above changes in element properties can be global or local changes to the model. Global changes have the effect of operating on all frequencies. Mode shapes will not change much with global changes. Local changes are used to tune mode shapes and frequencies selectively. For example, addition of a lumped mass affects the shape of the modes with large displacements at the points of additional mass. Mode shapes with no displacement at points of added mass will not change. Local stiffness changes have the same effect.

Tracking the Tuning Process

There are two requirements in tracking the model tuning progress. The first is an error function to measure the progress and set the goal of the tuning process. The second is a pictorial representation of the mode shapes to identify the modes and track shape changes.

The error function can be formed from mode shape or frequency differences. The first is of the form of the absolute difference in displacement of the model's mode shapes and the measured mode shapes. This requires nodal displacement vectors for the measured shapes at the same points being used as node points in the model; however, the measurement grid is rarely as fine as the finite element grid. A function of this magnitude must be automated. It has a problem in that eigenvalue schemes normalize the eigenvectors and this must be accounted for. The difference in measured and calculated frequencies can be used to form an error function. This function could be the square root of the sum of the squares of the frequency differences. This function allows the higher frequencies to dominate the lower frequencies. The above method can be modified by weighting the frequency differences with their percent error.

The pictorial representation of the mode shapes is an absolute requirement to track and identify mode shapes. The graphics package used must have the ability to superimpose the mode shape over the undeformed structure. The picture can be enhanced by forming the deformed structure with dashed lines. The superimposed picture is used to locate node lines which are needed to identify and track modes. A hardcopy of the picture is also required so that mode shape changes can be tracked. The hardcopy does not have to be immediately available in order to proceed with the tuning process. The ability to view the mode shapes from different orientations may also be necessary to distinguish modes. The total process time needs to be minimized due to the requirement of identifying the mode shapes for each change of a parameter. An interactive graphics package and the ability to gain hardcopies would substantially reduce the time required between parameter changes. GCSNAST is such an interactive graphics package capable of superimposing shapes and viewing orientation changes (Ref 3). Distribution restrictions on this package will end by 1983.

III. Tuning the T-38 Horizontal Stabilizer Model

Introduction

NASTRAN finite elements are used to model the horizontal stabilizer (Ref 4). The model is composed of bar elements for the spar, leading edge, trailing edge, tip, root rib, and torque tube and plate elements for the skin-honeycomb sandwich area. An exploded view of the model is shown in Fig 3. In the context of the preceding chapter, this is a class 2 model.

The free-free boundary condition eigenvalue analysis was done using NASTRAN's Rigid Format 3. The eigenvalue extraction was done using the inverse power method with shifting points (Ref 5). This technique works well on large degree of freedom systems where only a few eigenvalues are to be obtained.

The T-38 stabilizer model has demonstrated insufficient stiffness in torsion and bending during static loading analysis. The model produces lower frequencies that the measured values with both free-free and aircraft installed bounday conditions. The error as a percentage of the measured frequency is fairly constant. The lower frequency mode shapes compare well with the measured shapes (Ref 6; 7). The higher frequency mode shapes were not available for aircraft installed boundary conditions. The free-free higher frequency mode shapes were not well defined because the measurement grid was not dense enough.

The number of eigenvalues extracted must be limited to make the eigenvalue analysis a useable technique. This can be accomplished by either reducing the 804 degrees of freedom of the model or limiting the frequency range of the eigenvalues to be extracted. The purpose of

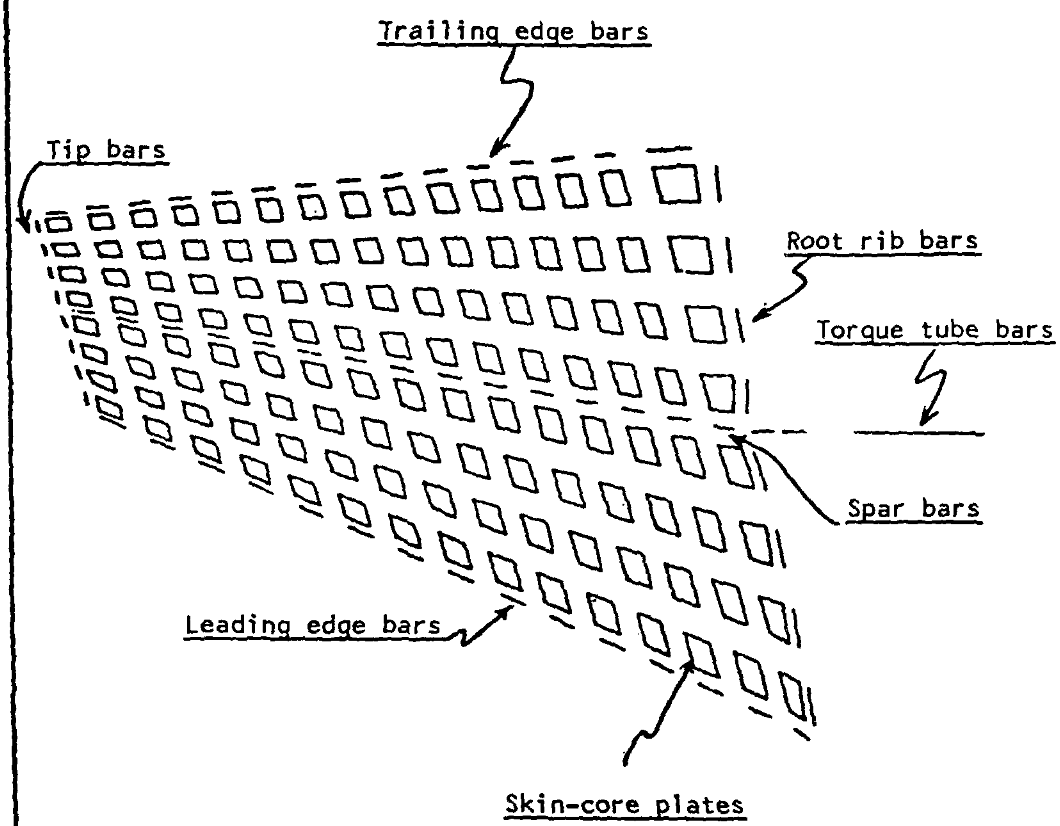


Figure 3. Exploded View of the Series 3 Model's Elements

the tuned model is to generate frequencies and mode shapes to be utilized in flutter analysis. The flutter analysis will be done using the lowest four to six modes. The eigenvalue extraction was therefore limited to a frequency range which bounded these modes. The degrees of freedom could have been reduced by eliminating the inplane rotation and translations which are usually eliminated for flutter analysis. The eigenvalue analysis took more computational time with the degrees of freedom removed through Guyan reduction than if the degrees of freedom had not been removed. The frequencies were also changed when the degrees of freedom were reduced. Therefore the reduction of degrees of freedom was not incorporated in this analysis.

Variables Chosen to Tune the T-38 Stabilizer

Several properties of the bar and plate elements were chosen to tune the model's frequencies. The desired effects of the changes were to increase all the frequencies by about the same percentage and not change the mode shapes. The frequency errors were considered to be caused in part by the model's lack of torsion cell simulation. Parameters were chosen to correct this error. The parameters were changed in increments of 10% in most cases. This increment was chosen to measure the effect of one parameter relative to the other parameters.

The modulus of elasticity and shear modulus were the material properties chosen to change the model's stiffness. Their values were increased for all the plate and bar elements except the torque tube and inboard quarter of the spar. The torque tube stiffness was considered to have little effect on the free-free modal frequencies. The inboard quarter of the spar was expected to have a lesser affect than the other spar elements.

The cross sectional properties chosen to tune the model were the bending moment of inertia and the polar moment of inertia. These parameters were chosen so that the bending and torsion modal frequencies could be changed separately. The polar moment of inertia of the spar was considered one possible parameter for correcting the model's lack of shear flow simulation. Both the inertia values were increased for the spar, trailing edge and leading edge elements.

Mass was also chosen as a tuning parameter. A decrease in the model's mass will increase the model's frequencies. The structural mass was changed by decreasing the density of all of the elements evenly. The non-structural mass was not chosen as a parameter. The non-structural mass was deemed more suitable for changing mode shapes which was not desired.

The thickness of the plates was chosen as a variable to change the torsional stiffness. Appendix A shows that an 82% increase of a plate thickness is required if a flat plate of the same width is used to model a rectangular hollow section in torsion. The thickness of the plate elements was increased by changing the core thickness or height in the Bulk Data Generator, which builds the finite element cards for NASTRAN. The core thickness values are used in the calculation of the bending moment of inertia, polar moment of inertia and cross sectional area of the plates and bars. The core thickness parameter will increase both torsion and bending modal frequencies.

The modulus of elasticity, shear modulus, bending moment of inertia, polar moment of inertia, mass and core thickness are the six parameters used in the model tuning process. Each parameter value was changed for all the model elements listed for that parameter at one time.

Tracking the Tuning Process

The shifts in modal frequency due to changes in the parameters were tracked using the mode shapes and an error function. The mode shapes were critical in frequency tracking to make sure mode shapes were not distorting and to identify modes. Identifying mode shape and frequency pairs is very important if a change in a parameter were to increase one frequency past another frequency. The error function was the sum of the squares of the percent difference in the first and second torsion frequencies and second bending frequency. The first bending frequency was not found in the experimental measurements and therefore was not included in the error function.

The modal mass and modal stiffness values calculated by NASTRAN were found to be very useful for mode separation. Their changes were monotonic with changes of parameters. Figures 4 and 5 are samples of modal mass and modal stiffness changes with respect to changes in the core thickness.

Sensitivity of the Model's Frequencies to the Parameters

Appendix B contains a table of the frequency changes with changes in the parameters. The core thickness was found to be the most effective variable for tuning both torsion and bending frequencies. The spar was found not to be a dominating structural member because it's bending moment of inertia and polar moment of inertia have very little effect. The modulus of elasticity, shear modulus and density parameters produced nominal frequency changes. The mode shapes were found to distort with large increases in the modulus of elasticity parameter.

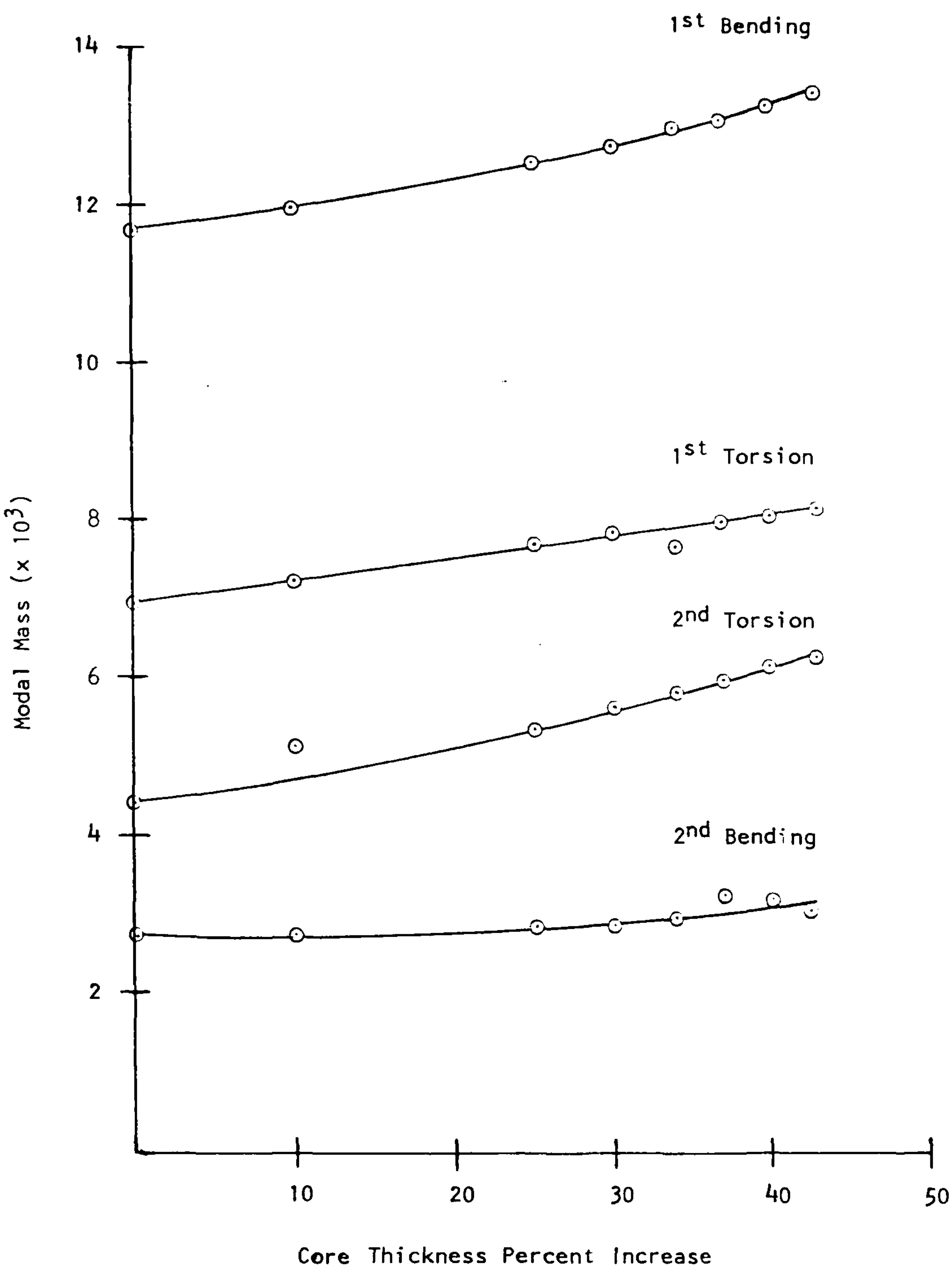


Figure 4. Variation of Modal Mass With Change in Core Thickness

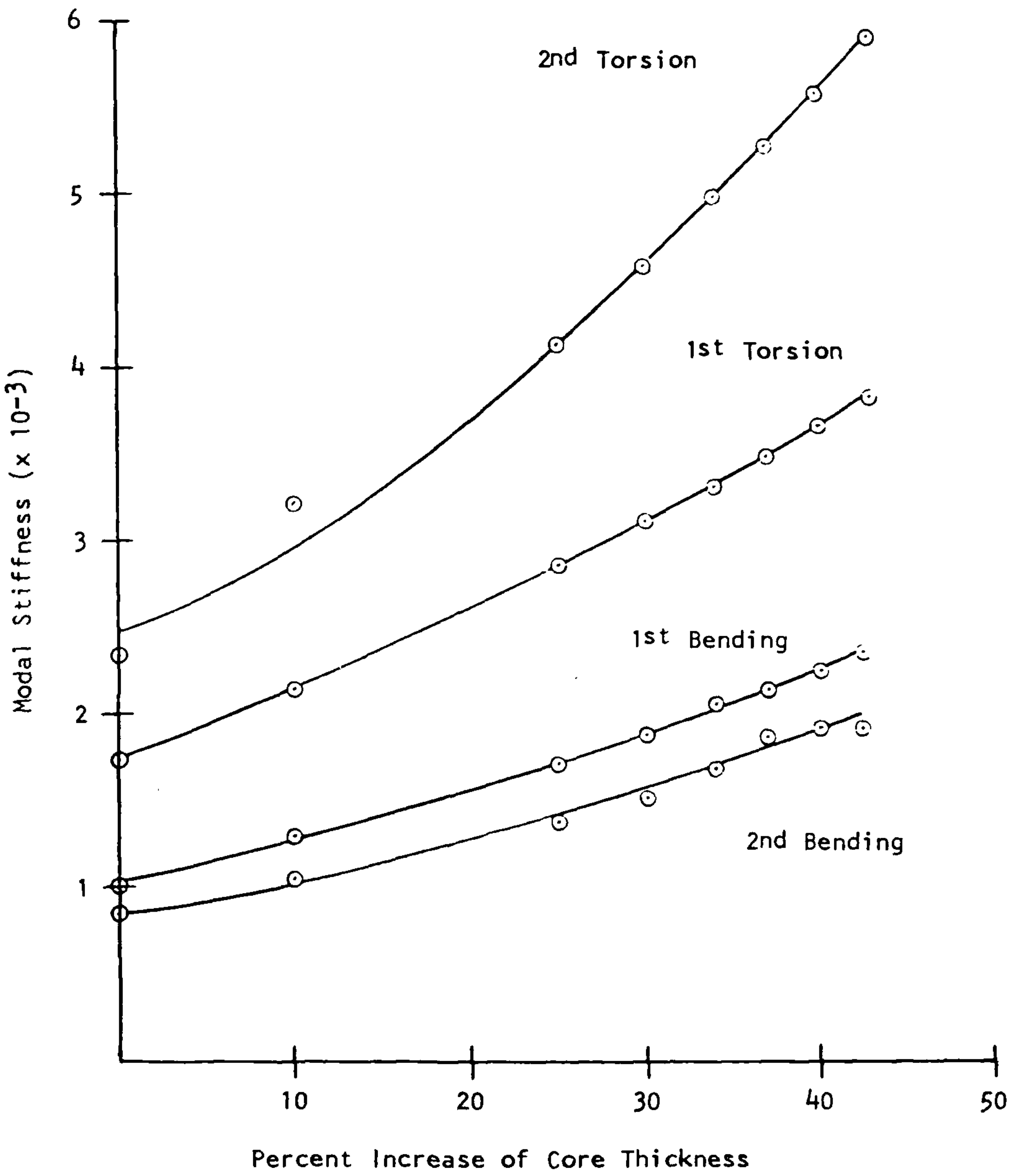


Figure 5. Variation of Model Stiffness with Change in Core Thickness

Conclusions for Free-Free Model Tuning

An increase of core thickness of 37% is considered the best tuned model without changing the type of elements of the model. Figure 6 shows the error function versus the change in core thickness. This parameter was the most sensitive and affects torsion and bending frequencies equally (Fig 7). Table 1 lists the frequencies of the untuned model, tuned model, and measured frequencies. The mode shapes correlate well with the measured shapes. The tuned and measured mode shapes can be seen in figures 8 thru 14.

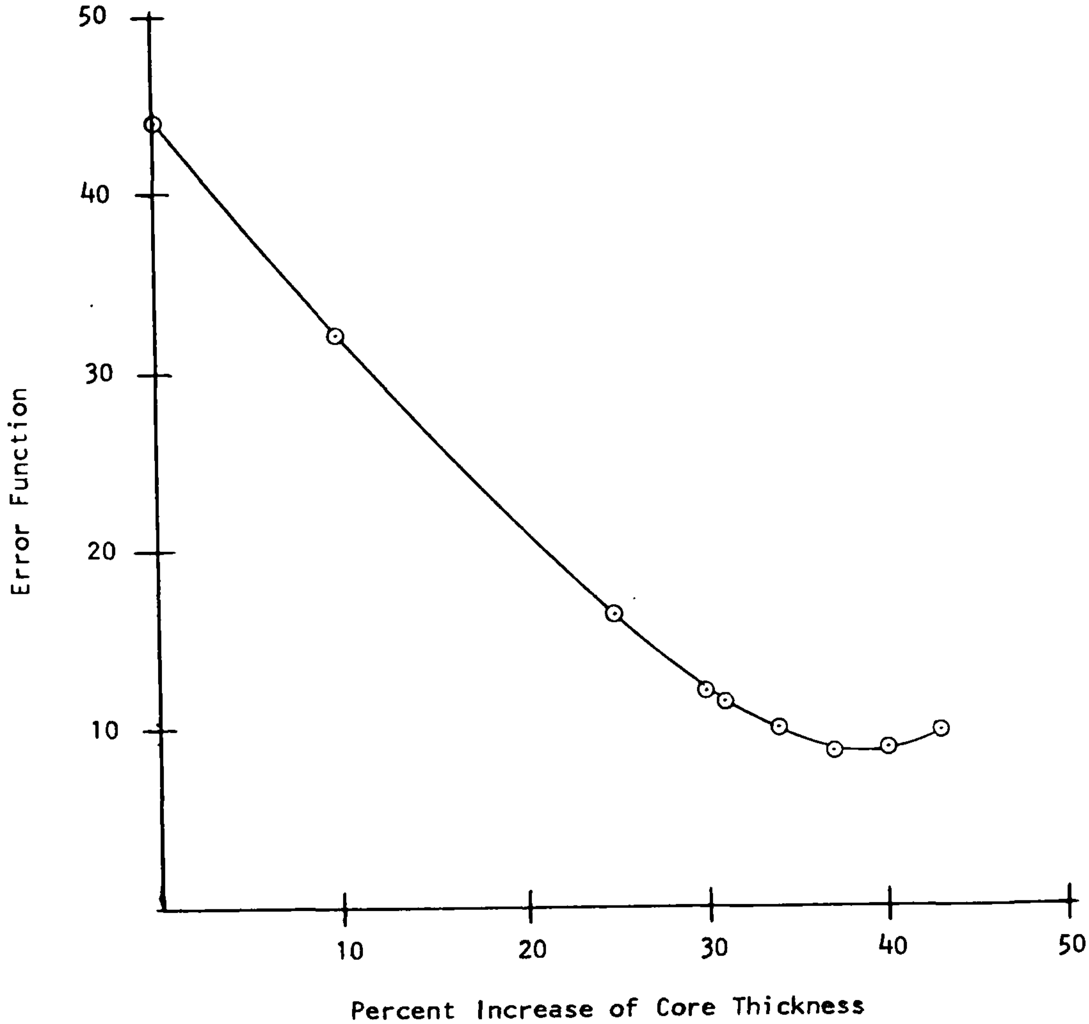


Figure 6. Frequency Error Function Versus Change in Core Thickness

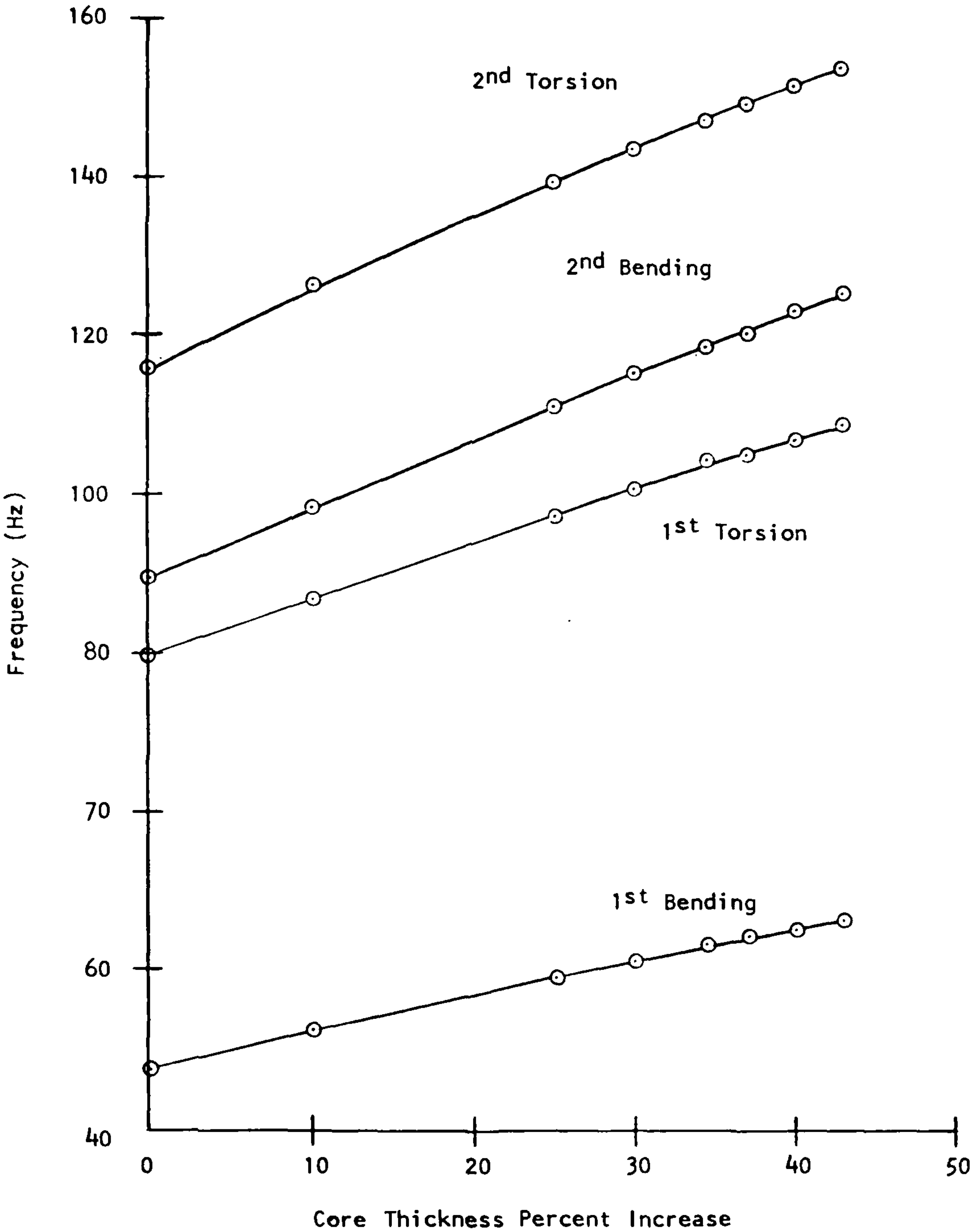


Figure 7. Frequency Versus Change in Core Thickness

TABLE 1

MEASURED AND CALCULATED

FREE-FREE MODAL FREQUENCIES

MODE	EXPERIMENTAL FREQUENCY Hz (Ref 7)	NASTRAN UNTUNED MODEL Frequency Hz	NASTRAN TUNED MODEL Frequency Hz
1st Bending	-NA-	47.8	64.5
1st Torsion	100	79.8	105.5
2nd Bending	124	89.7	121.0
2nd Torsion	160	115.8	149.8

-NA- Not Available

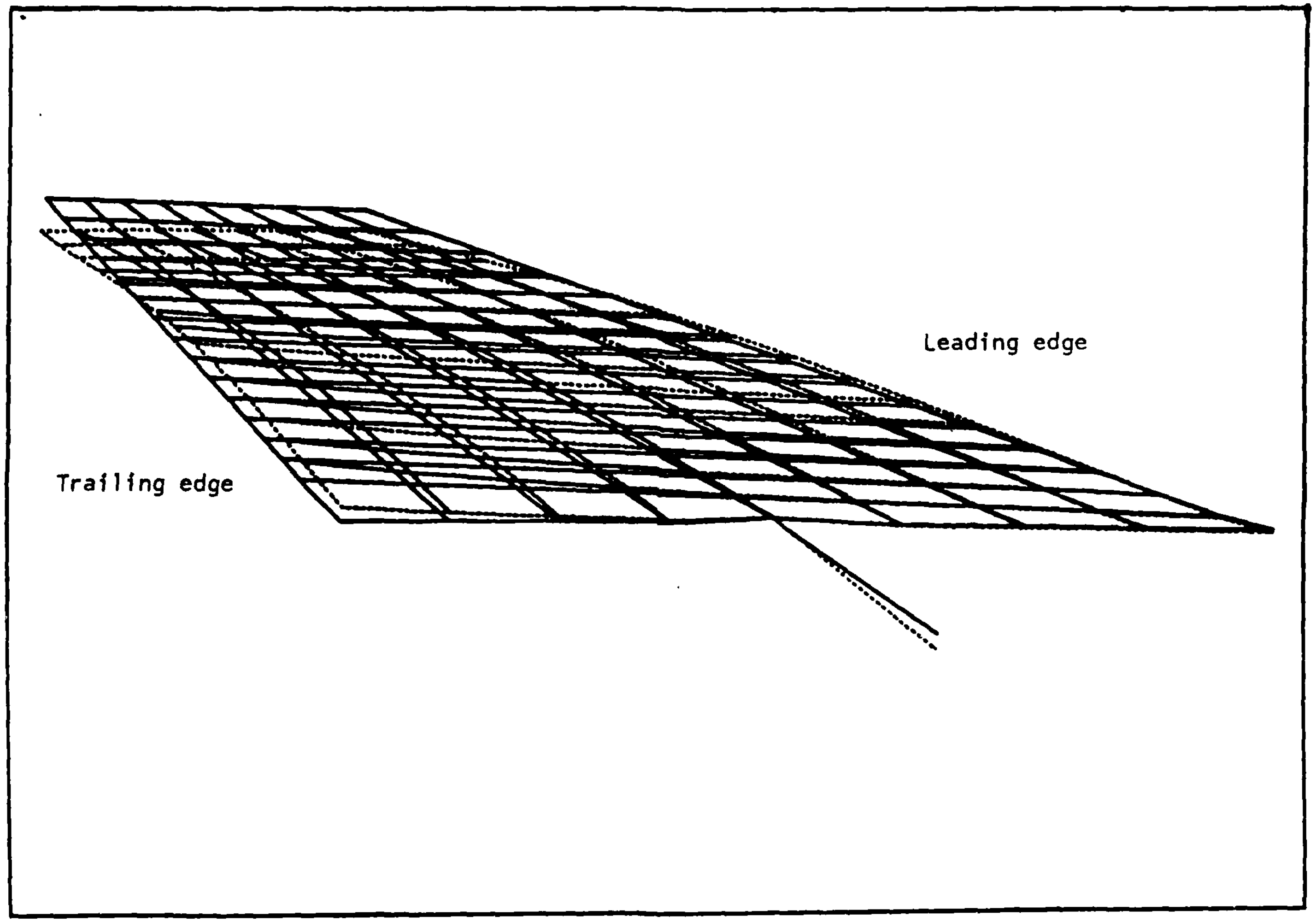


Figure 8. NASTRAN Calculated Free-Free 1st Bending Mode, 64.5 Hz
Airfoil Thickness Increased 37%

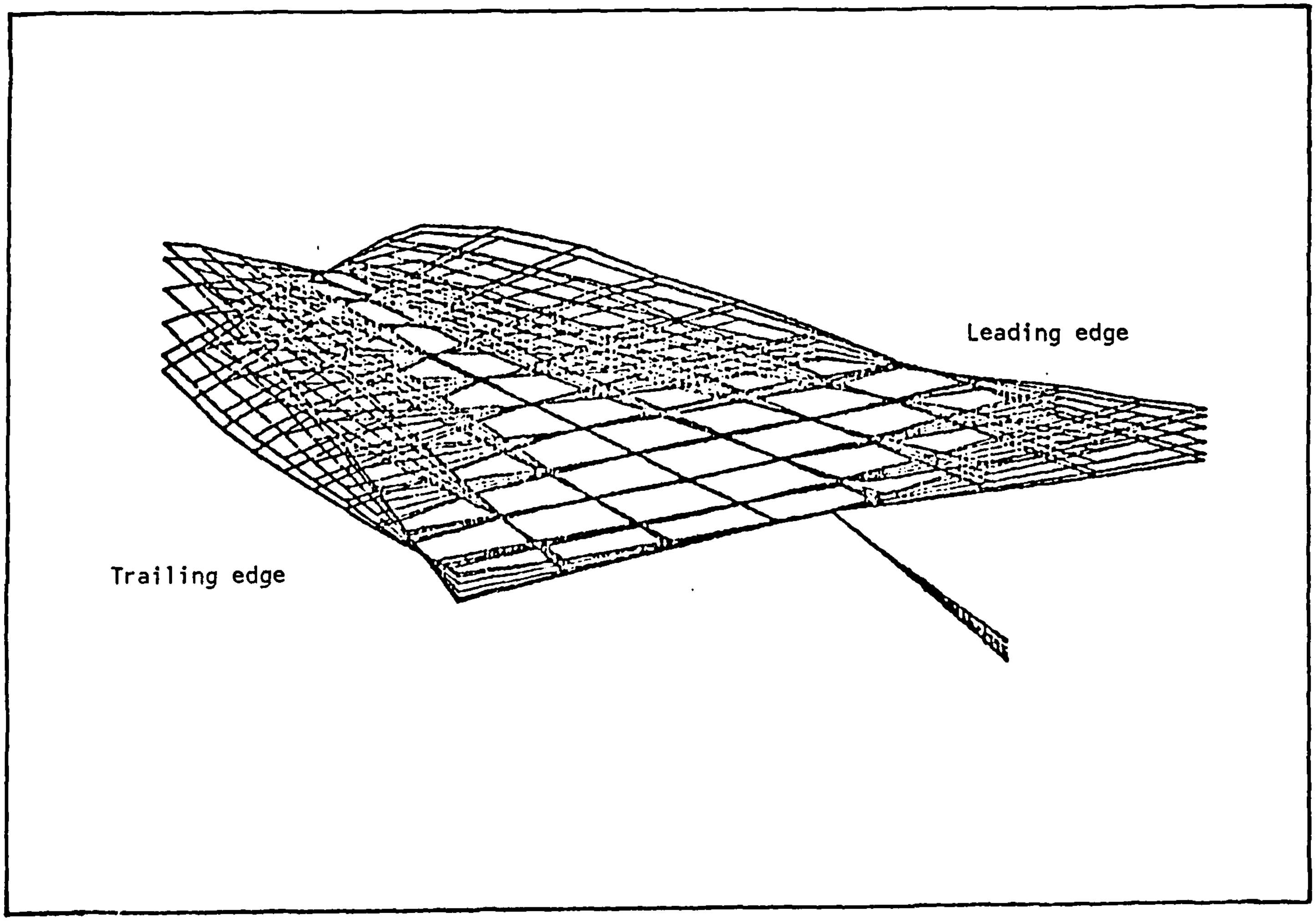


Figure 9. Thomson's Measured Free-Free 1st Torsion Mode, 100 Hz (Ref 7)

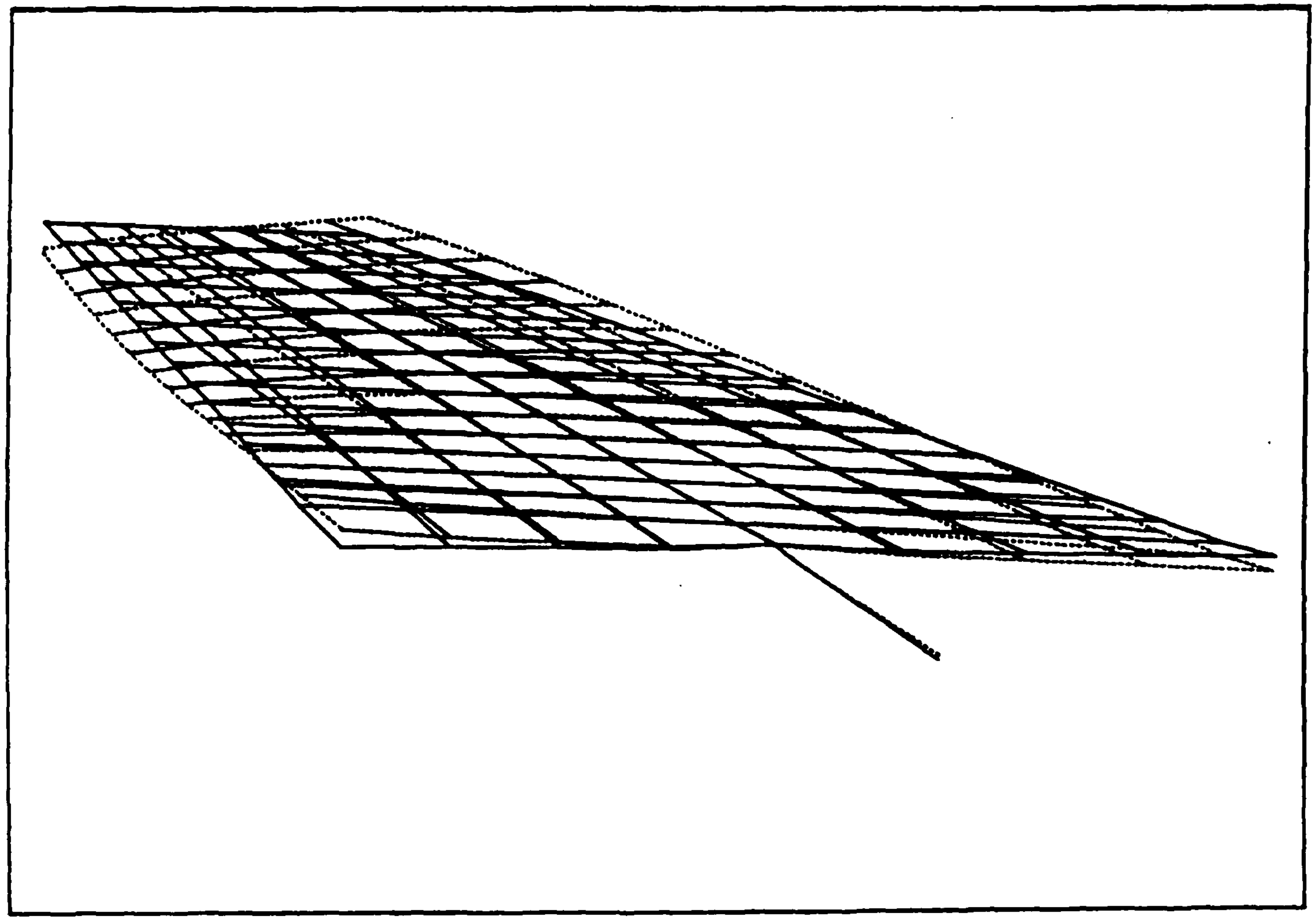


Figure 10. NASTRAN Calculated Free-Free 1st Torsion Mode, 105.5 Hz
Airfoil Thickness Increased 37%

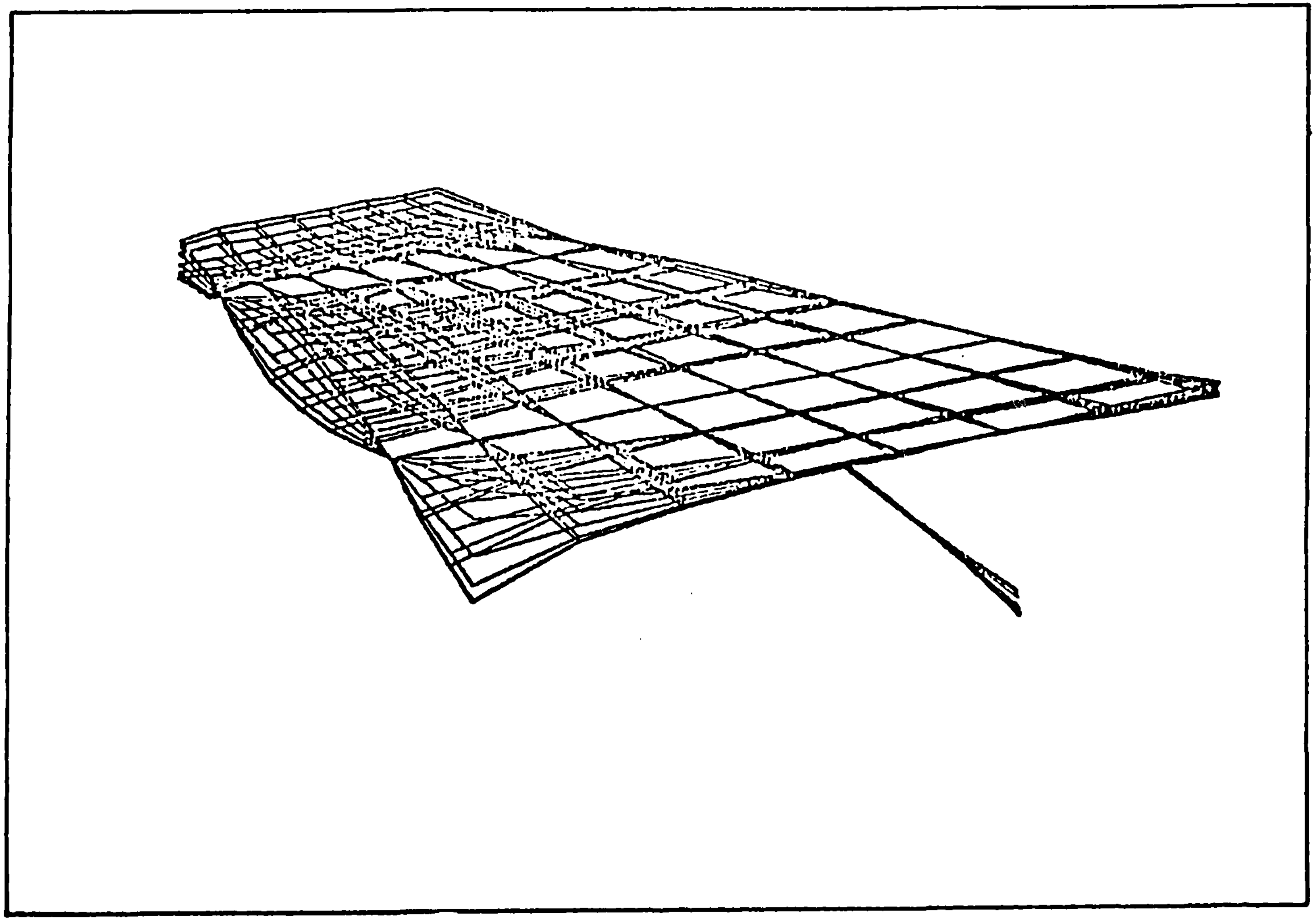


Figure 11. Thomson's Measured Free-Free 2nd Bending Mode, 124 Hz (Ref 7)

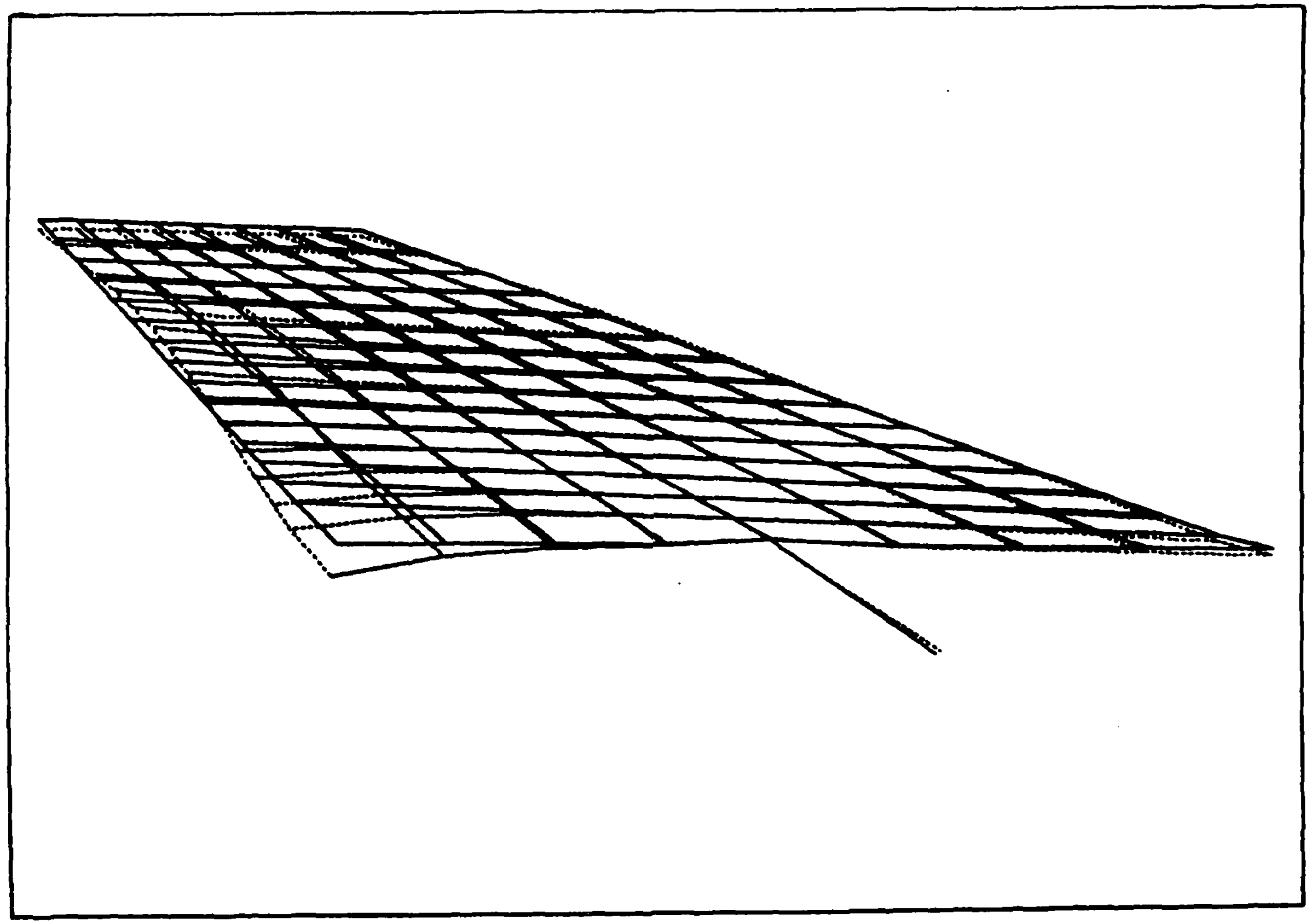


Figure 12. NASTRAN Calculated Free-Free 2nd Bending Mode, 121.0 Hz
Airfoil Thickness Increased 37%

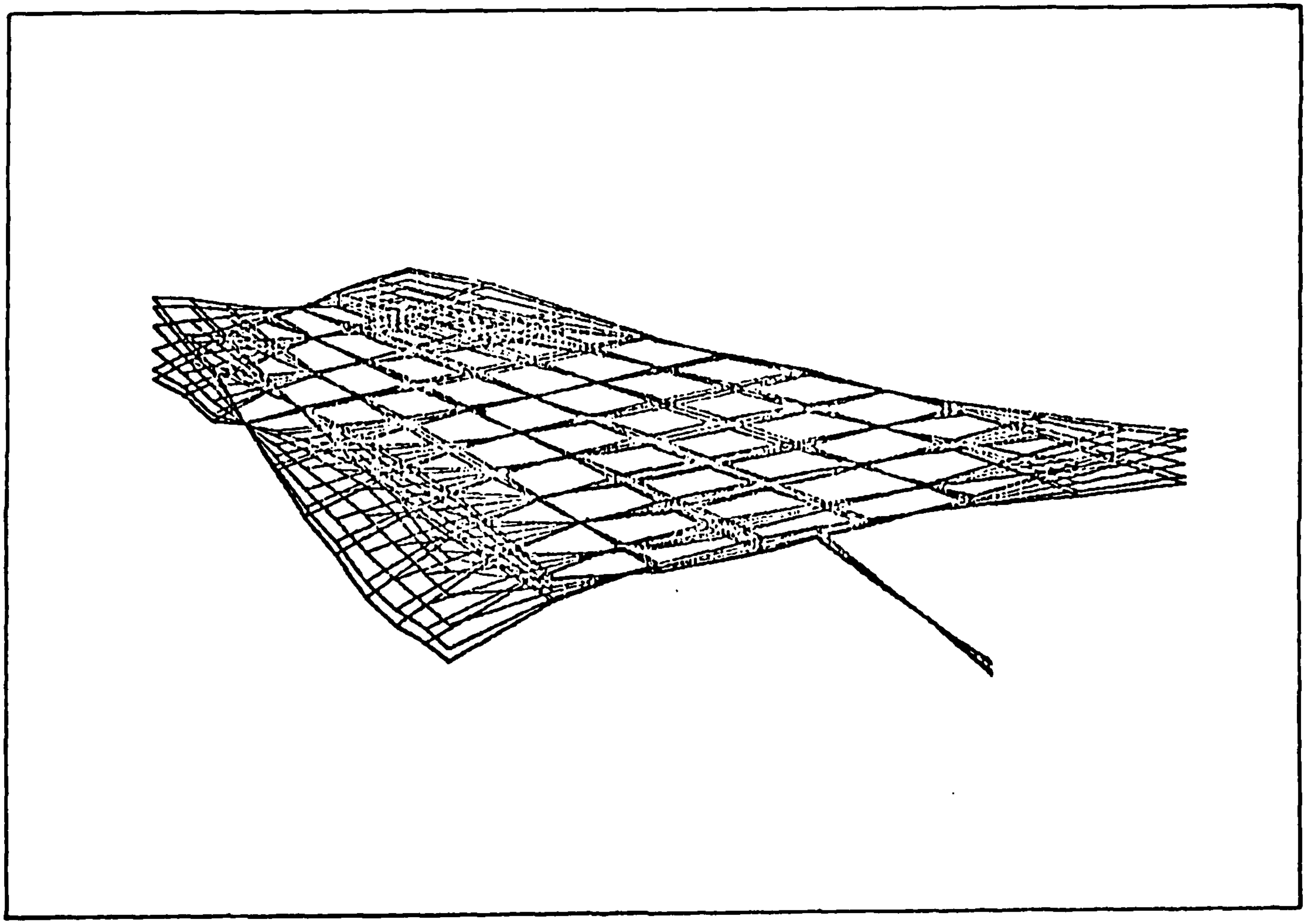


Figure 13. Thomson's Measured Free-Free 2nd Torsion Mode, 160 Hz (Ref 7)

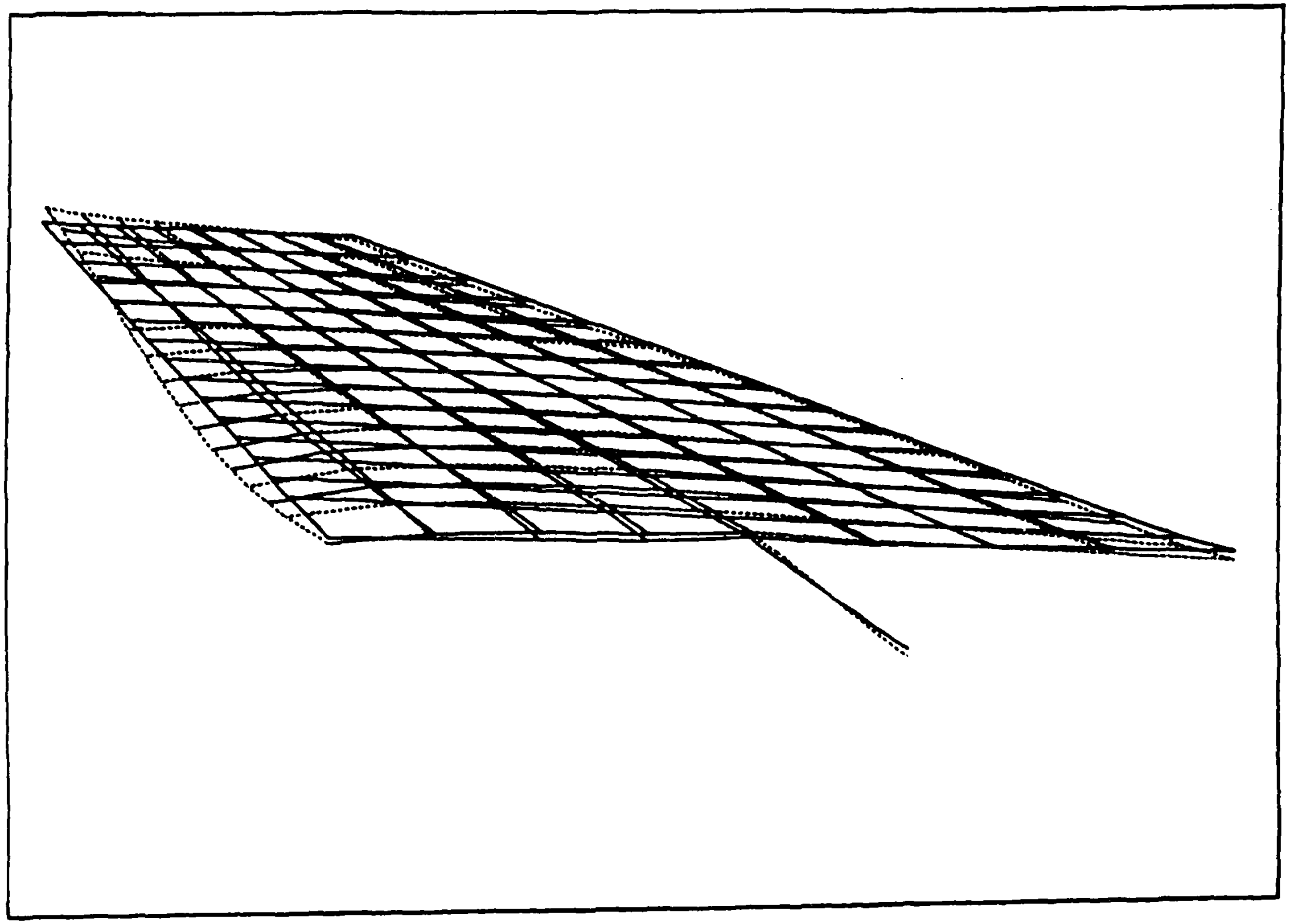


Figure 14. NASTRAN Calculated Free-Free 2nd Torsion Mode, 149.8 Hz
Airfoil Thickness Increased 37%

IV. Eigenvalue Analysis of the Aircraft Installed Model

Introduction

Measured modes and frequencies are available in a report by Rohlman (Ref 8). These modes and frequencies were measured during a ground vibration test on a Canadian F-5. The measurements were accomplished with both hydraulic control systems functioning.

Modeling of the control system stiffness is very important. This stiffness dominates the first torsion mode frequency. In the first torsion mode the stabilizer acts like an inertia disk attached to the torque tube which is restrained by a torsion spring (control system stiffness). In an investigation by Southwest Research Institute the control system stiffness was found by tuning the first torsion mode to a frequency reported by Northop (Ref 10). Northrop's frequency was for a rigid stabilizer. A value of the stiffness of the control system was investigated by Northrop (Ref 9). They derived an equation with the hydraulic cylinder stiffness and stiffnesses of the attachment members as parameters. Values for the attachment members were calculated. A test was performed to measure the hydraulic cylinder linear spring rate at various temperatures. The control system stiffness can be calculated using the values for attachment members and a value for the spring rate; however, a final value was not calculated due to the temperature dependence.

Eigenvalue Analysis

The eigenvalue analysis was accomplished using the tuned model and aircraft installed boundary conditions. The boundary conditions were simulated using NASTRAN's single point constraint to model the bearing attachment and for the centerline coupling between left and right stabilizers. The scalar spring property and connectivity (CELAS2) was used to model the control system connection and stiffness.

The frequencies and mode shapes calculated were compared to frequencies and mode shapes measured by Rohlman and calculated by Northrop. The CELAS2 value was varied to align the frequencies of the first torsion mode.

The first two modes with the installed boundary conditions are not the same modes as the first two in the free-free condition. The first two modes with installed boundary conditions are basically rigid stabilizer modes with bending of the torque tube and the torsion of the control system stiffness. The third and fourth modes are comparable to the free-free conditions first and second modes respectively.

Results

The frequencies measured and calculated are listed in Table 2. The CELAS2 value required to align the calculated first torsion frequency with Rohlman's first torsion frequency was 9.75×10^6 in-lbs/rad. This value is considerably higher than the 2.54×10^6 value calculated by Lassiter for both hydraulic systems operating. A CELAS2 value of 4.40×10^6 aligned the NASTRAN and Northrop calculated first torsion frequencies. The mode shapes for both CELAS2 values are very close to being the same so only the modes calculated with a CELAS2 value of 9.75×10^6 are included. Figures 15 thru 23 are the mode shapes calculated with NASTRAN, by Northrop and measured by Rohlman (Eglin). Northrop's and Rohlman's mode shapes have been extrapolated to a 3 - Dimensional view.

TABLE II

COMPARISON OF NASTRAN's AND NORTHROP's

CALCULATED FREQUENCIES AND

EGLIN's MEASURED FREQUENCIES

WITH AIRCRAFT INSTALLED BOUNDARY CONDITIONS

MODE	NAI FREQUENCY Hz	EGLIN GVT FREQUENCY Hz	NASTRAN TUNED MODEL CELAS2=4.40×10^6 Hz	CELAS2=9.75×10^6 Hz
1st Bending	17.61	18.52	17.45	17.49
1st Torsion	44.89	50.20	44.41	50.02
2nd Bending	78.76	70.69	75.11	75.54

NOTES:

1. NAI calculations were done simulating one hydraulic system functioning.

2. The Eglin GVT was conducted with both hydraulic systems functioning.

3. The CELAS2 number is the modeled control system stiffness value. The 1st Torsion frequency of NASTRAN was tuned to equal the NAI and Eglin GVT 1st Torsion frequencies to calculate the control system stiffness values. The units are in-lbs/rad.

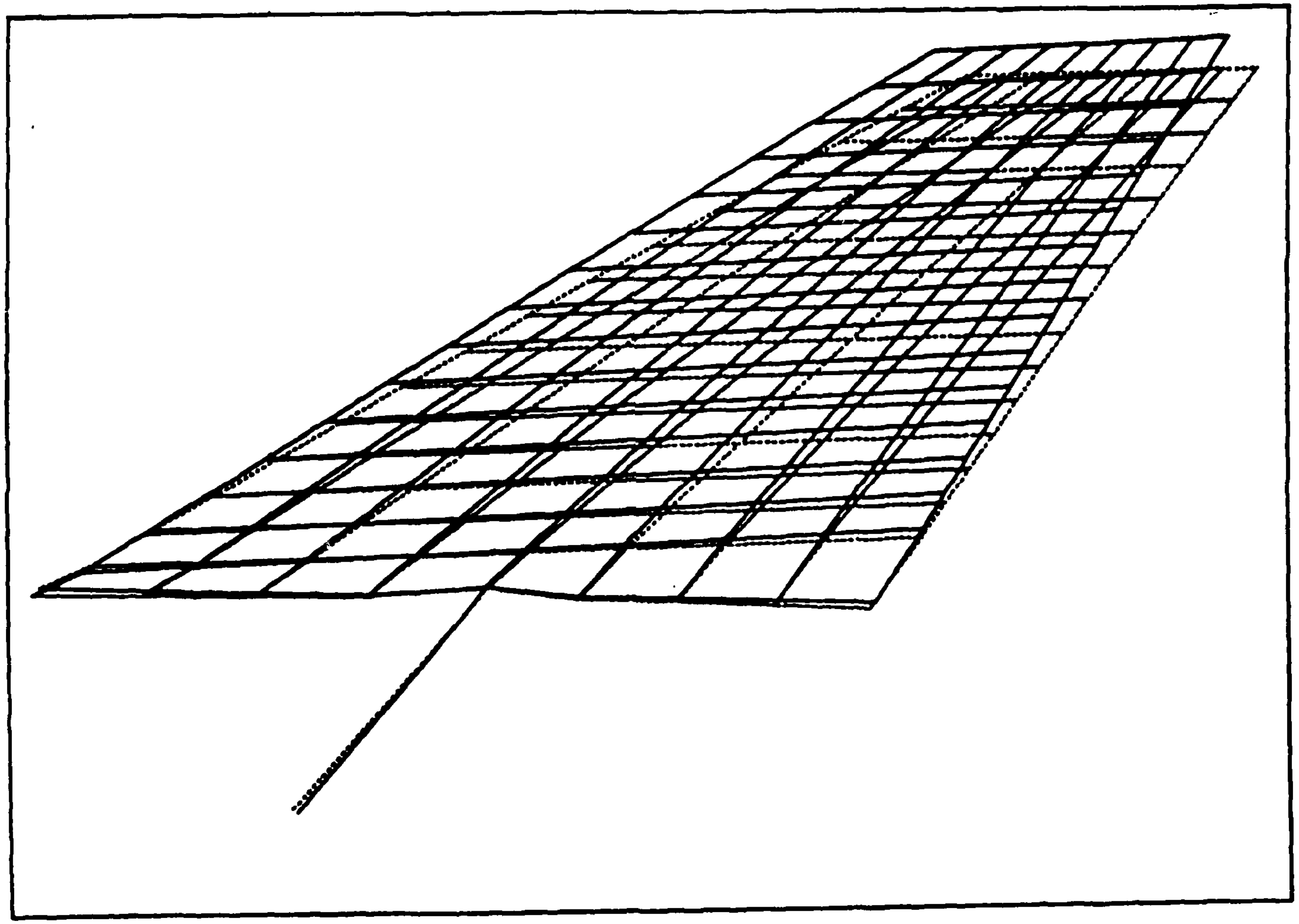


Figure 15. NASTRAN Calculated Aircraft Installed 1st Bending Mode, 17.5 Hz
Control Stiffness was 9.75×10^6 in-lbs/rad

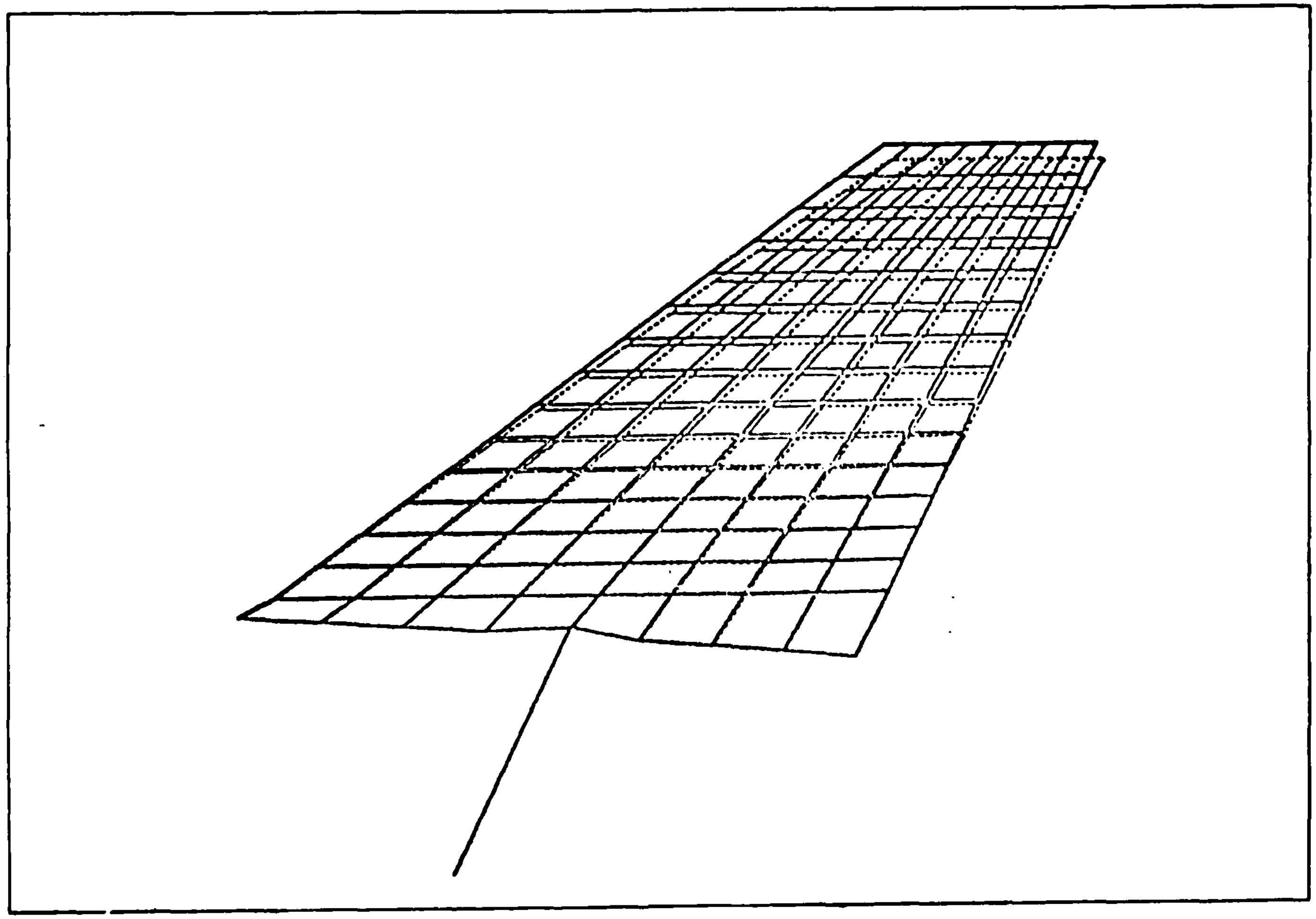


Figure 16. Eglin GVT Measured Aircraft Installed 1st Bending Mode, 18.5 Hz
Both Hydraulic Systems Operating
(Ref 6; 8)

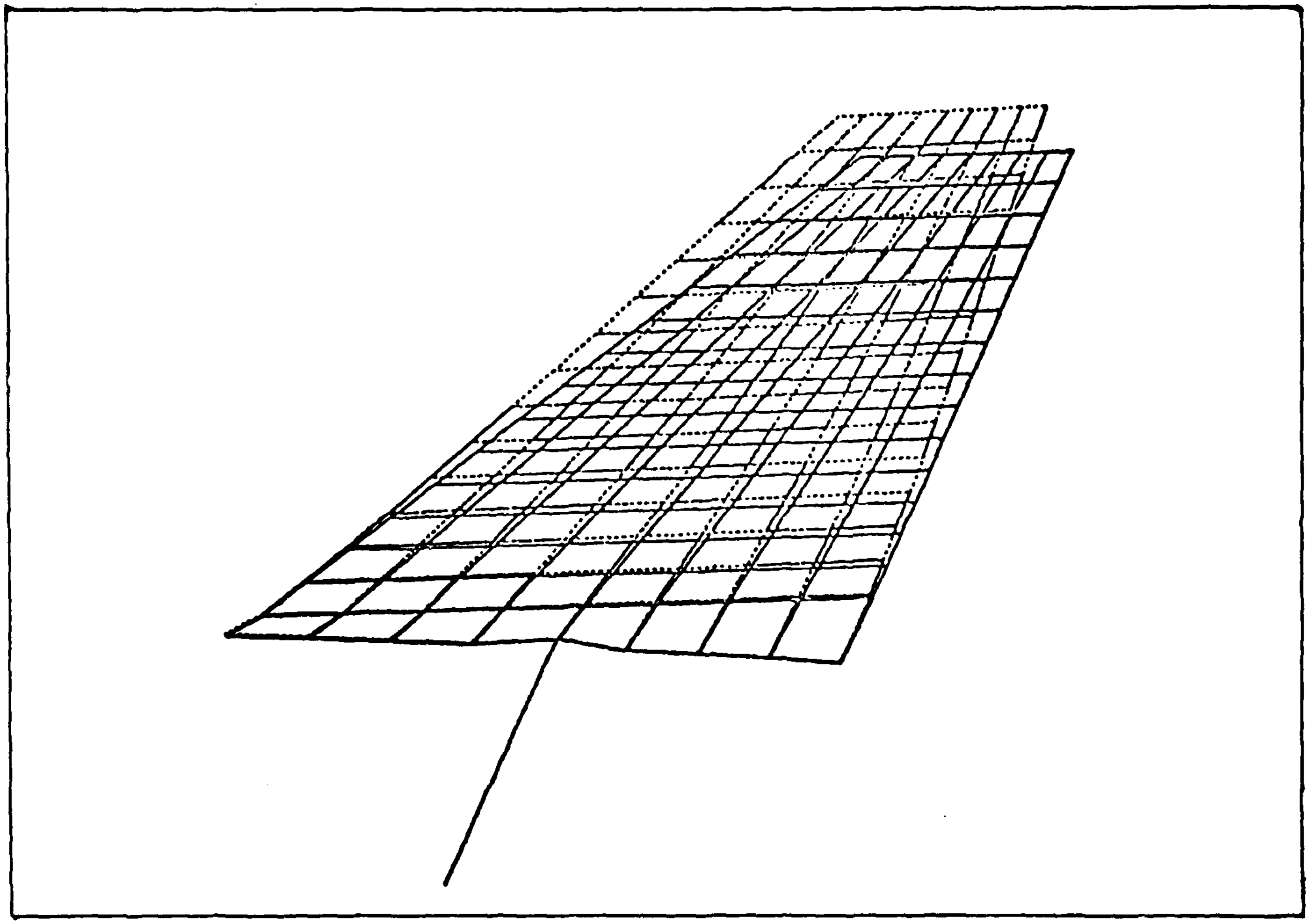


Figure 17. Northrop's Calculated Aircraft Installed 1st Bending Mode, 18.8 Hz One Hydraulic System Operating (Ref 6)

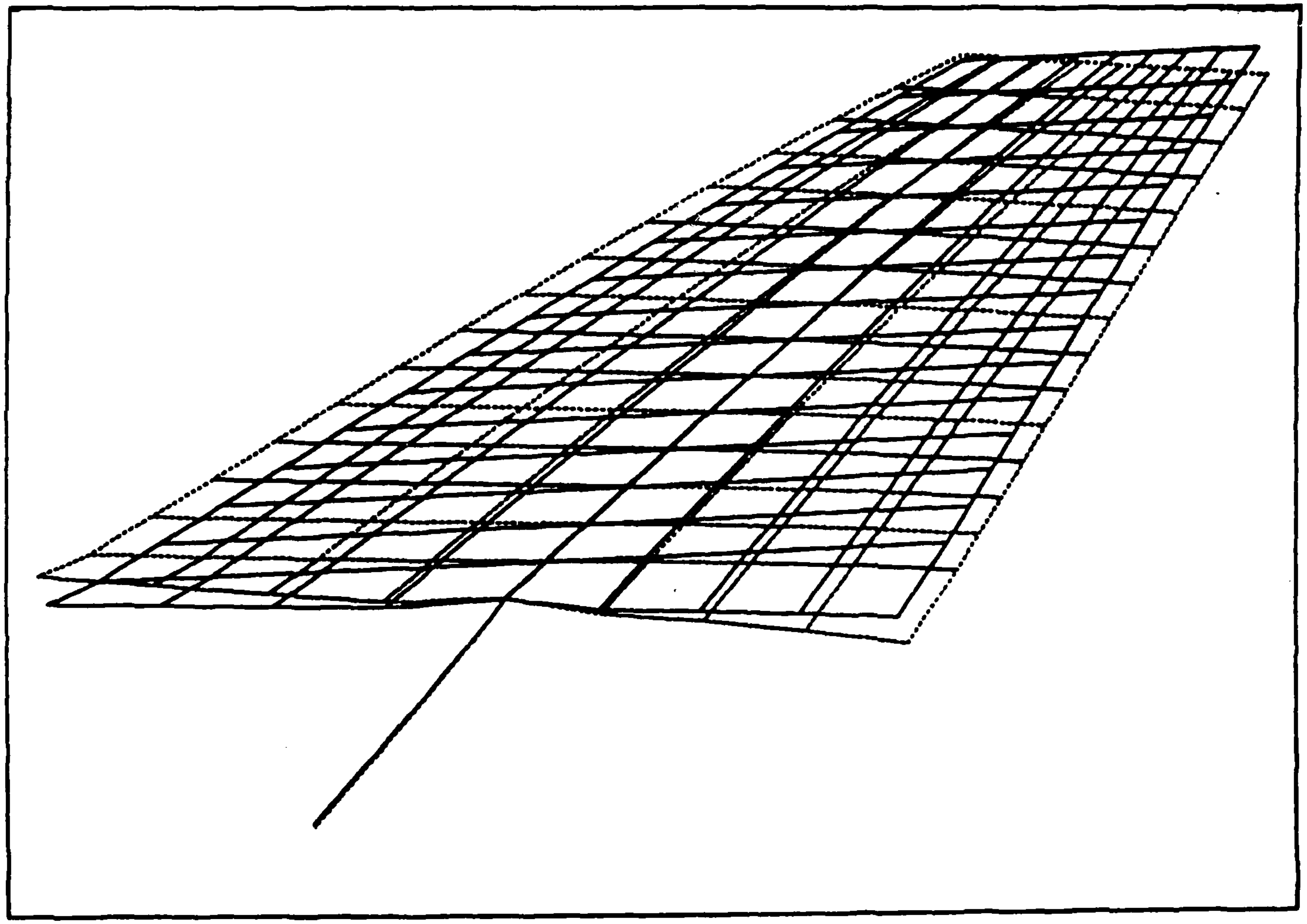


Figure 18. NASTRAN Calculated Aircraft Installed 1st Torsion Mode, 50.0 Hz Control Stiffness was 9.75×10^6 in-lbs/rad

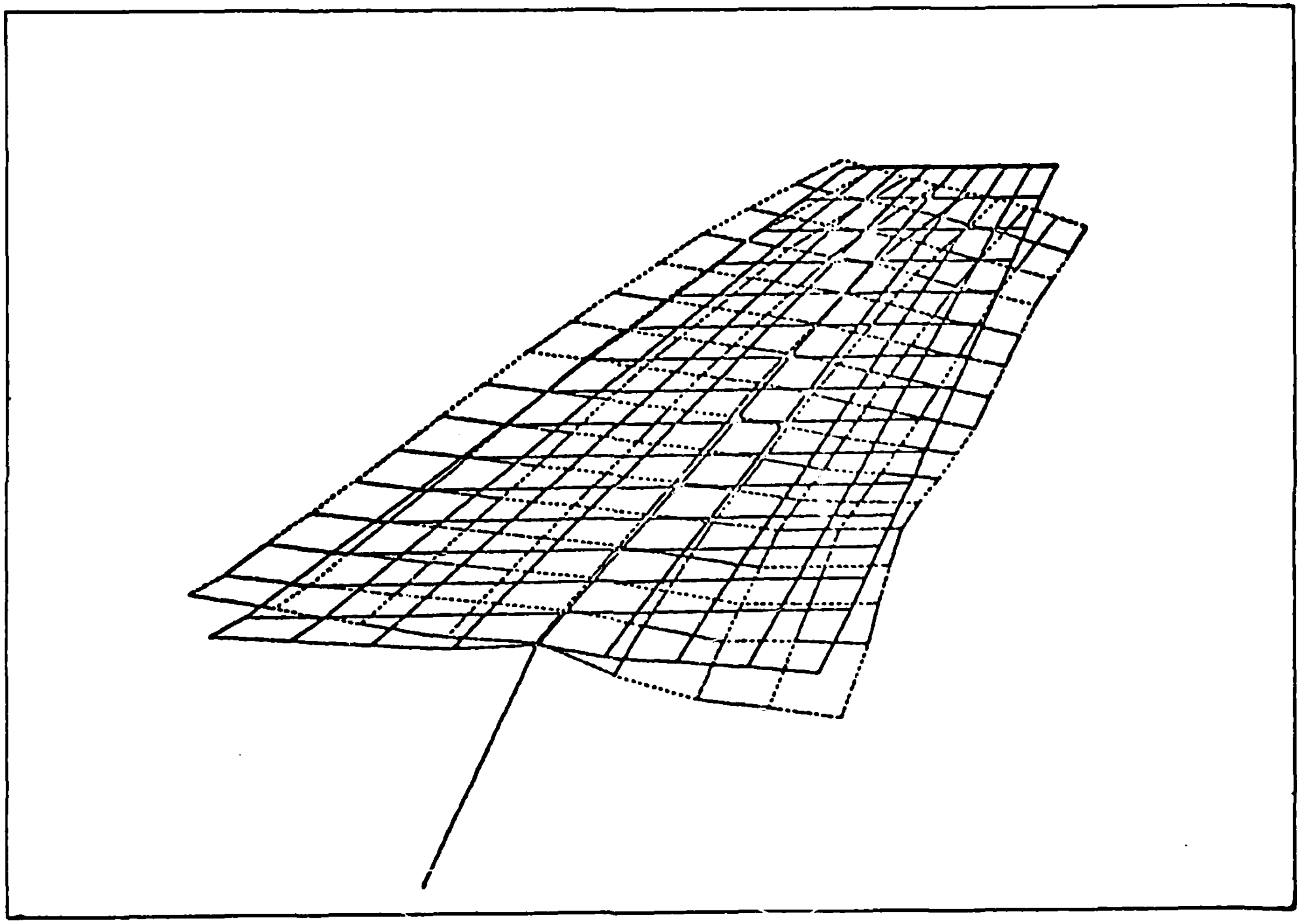


Figure 19. Eglin GVT Measured Installed 1st Torsion Mode, 50.2 Hz
Both Hydraulic Systems Operating
(Ref 6; 8)

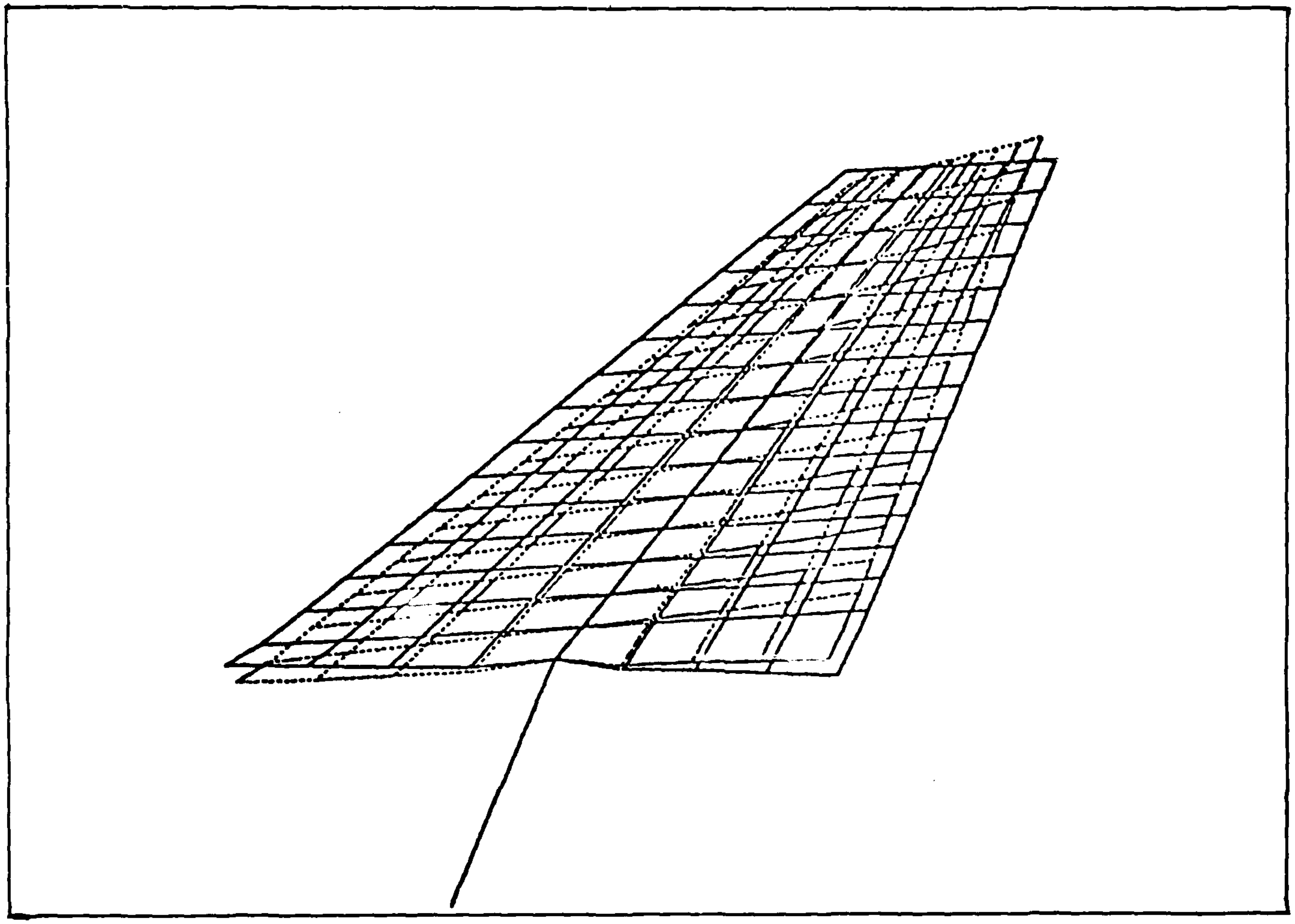


Figure 20. Northrop's Calculated Aircraft Installed 1st Torsion Mode, 44.9 Hz
One Hydraulic System Operating
(Ref 6)

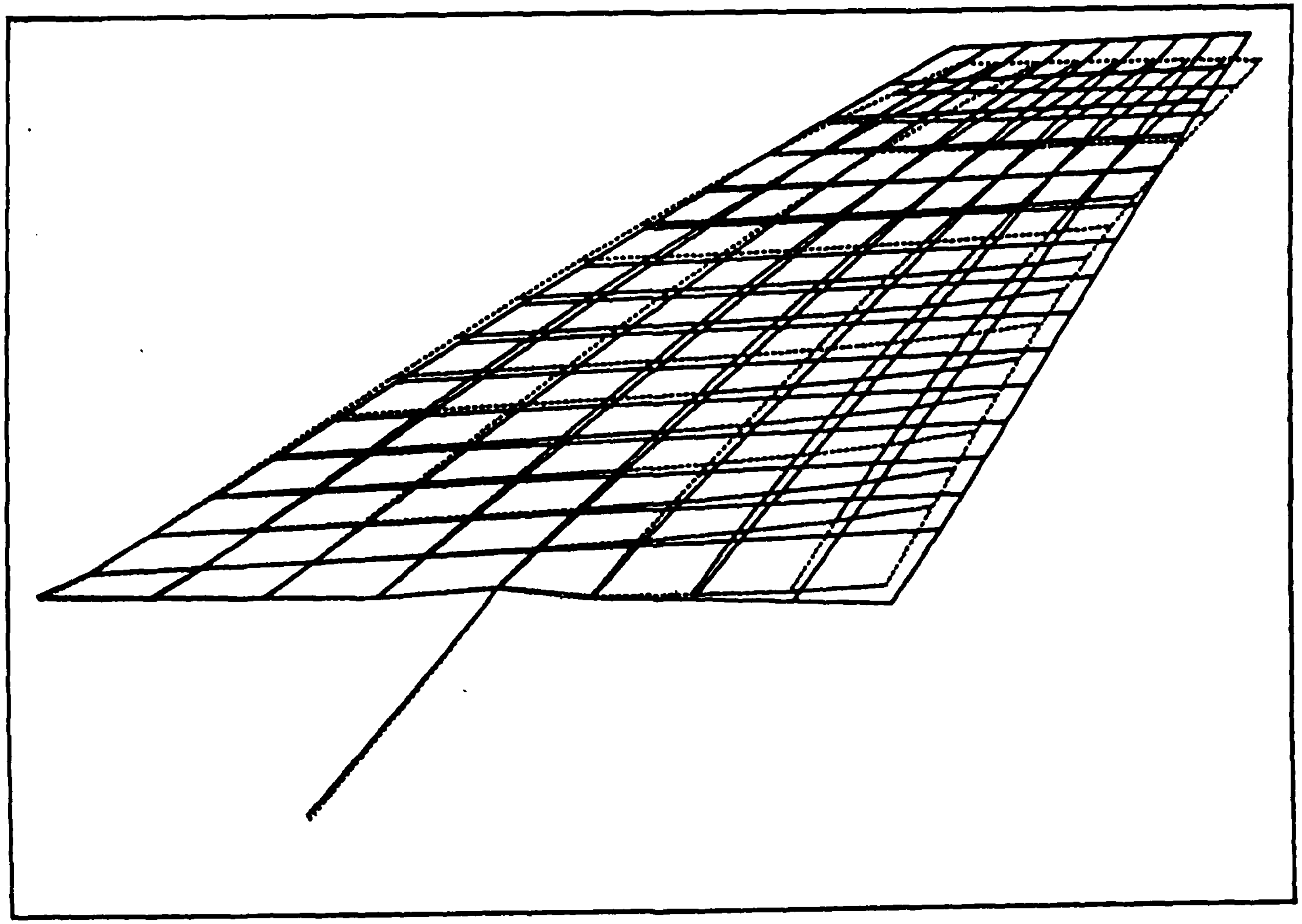


Figure 21. NASTRAN Calculated Aircraft Installed 2nd Bending Mode, 75.5 Hz
Control Stiffness was 9.75×10^6 in-lbs/rad

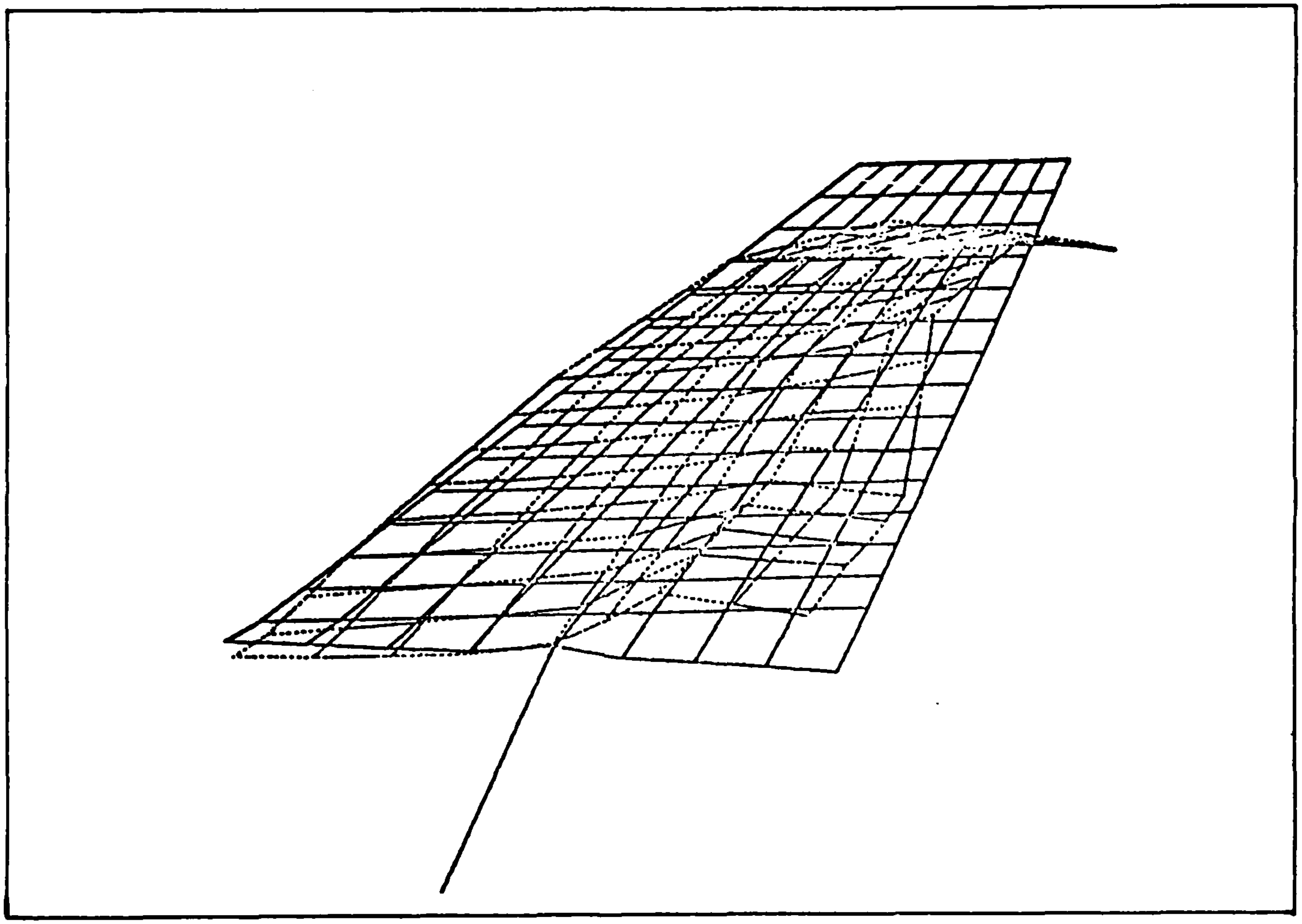


Figure 22. Eglin GVT Measured Aircraft Installed 2nd Bending Mode, 70.7 Hz
Both Hydraulic Systems Operating
(Ref 6; 8)

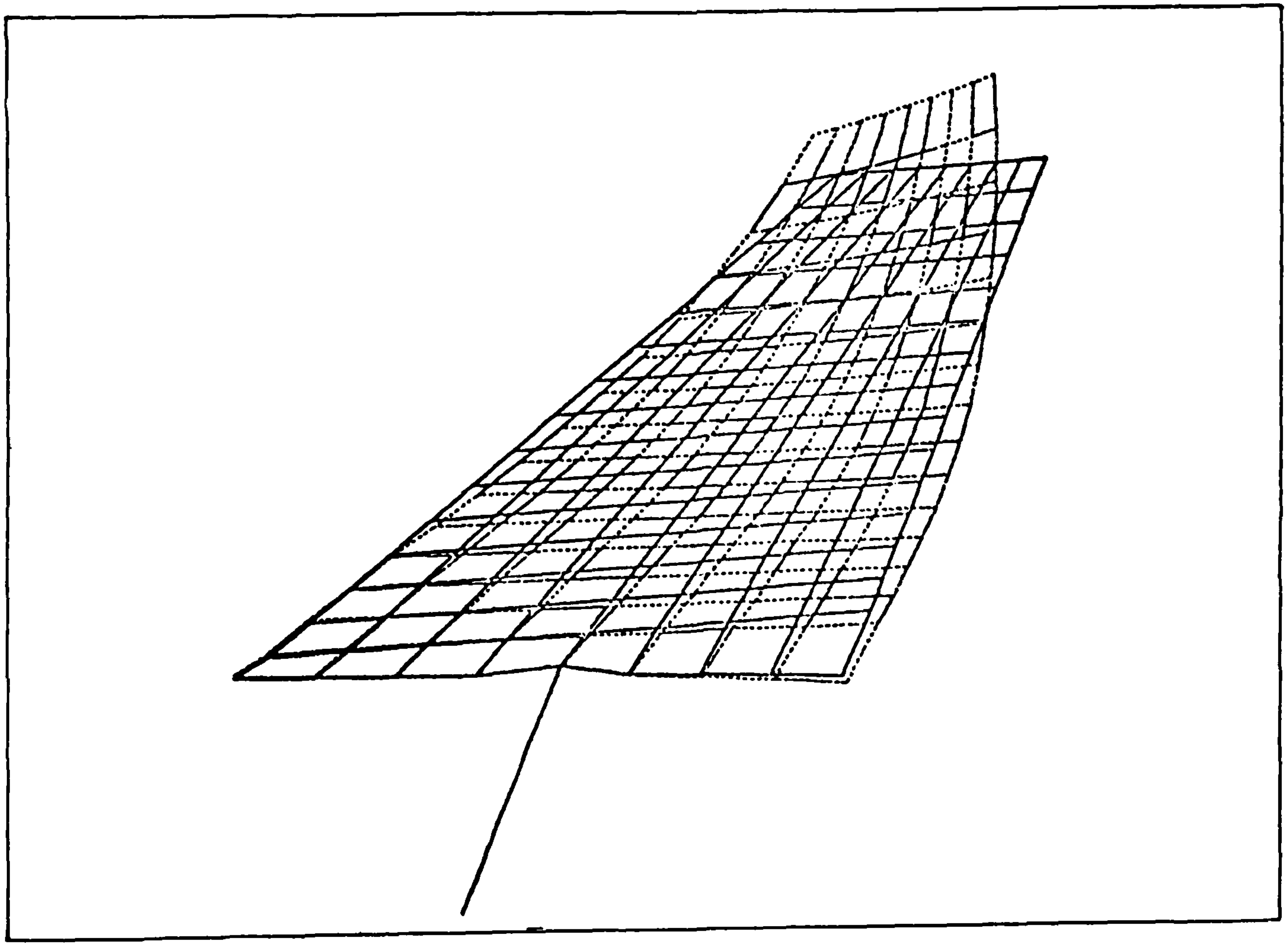


Figure 23. Northrop's Calculated Aircraft Installed 2nd Bending Mode, 78.8 Hz
One Hydraulic System Operating
(Ref 6)

Conclusions

The frequencies and mode shapes of the tuned model compared much better with the measured frequencies than the untuned model. The installed stabilizer analysis does not verify the tuning of the model accomplished in the free-free condition. This is due to insufficient modes in common.

V. Conclusions

A tuned model was obtained. An increase of the model's core thickness by 37% and a control system pitch stiffness of 4.40×10^6 produced a tuned installed model. The mode shapes ar~ very good and the difference between the model and measured frequencies is small. Therefore this model is considered to be suitable for use in analysis to determine the degradation of flutter speed caused by repairs.

VI. Recommendations

The static test results and model investigation should be incorporated with the dynamic analysis done in this investigation to verify the tuned model. The unsymmetric modes should be investigated to verify the torque tube stiffness. More investigation into the control system pitch stiffness value should be done. The pitch stiffness was reported by Northrop as being flutter critical. Therefore in order to gain confidence in absolute flutter velocities this value should be well defined. Flutter analysis procedures and repair simulation should be investigated before a useable package can be presented by San Antonio Air Logistics Center.

Bibliography

1. NAI-57-59. T-38A Horizontal Stabilizer. Structural Analysis, Hawthorne CA: Northrop Aircraft, Inc., October 1958.

2. Bruhn, E.F. Analysis and Design of Flight Vehicle Structures. Cincinnati OH: Tri-State Offset Co., 1965.

3. McVinnie, Bill, et al. GCNAST Manual. Wright-Patterson AFB, OH: Engineering Systems Development Department, Technical Computer and Instrumentation Center, August 1979.

4. NASA SP-222(04). The NASTRAN User's Manual, Level 17.5. Washington DC: Scientific and Technical Information Division, National Aeronautics and Space Administration, December 1977.

5. NASA SP-221(03). The NASTRAN Theoretical Manual. Washington DC: Scientific and Technical Information Division, National Aeronautics and Space Administration, March 1978.

6. Thomson, Roger K. Investigation of an Improved Flutter Speed Prediction Technique for Damaged T-38 Horizontal Stabilators Using Nastran. Wright-Patterson AFB, OH: Air Force Institute of Technology, December 1980.

7. Lassiter, John O. Initial Development for a Flutter Analysis of Damaged T-38 Horizontal Stabilators Using Nastran. Wright-Patterson AFB OH: Air Force Institute of Technology, March 1980.

8. Rohlman, William H. CF-5 Horizontal Stabilizer Ground Vibration Test. Eglin AFB FL: Structural Dynamics Laboratory, Air Force Armament Test Laboratory, (AFATL/DLJCS), October 1979.

9. NAI-58-813. Investigation of the Root Stiffness Properties of the T-38A Horizontal Stabilizer. Hawthorne CA: Northrop Aircraft, Inc., October 1958.

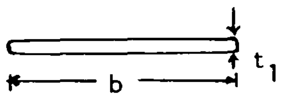
10. Burnside, O.H. Vibration Analysis of the T-38 Lead-In Fighter with the Addition of Fuselage Centerline Stores, Report No. 6. SWRI Project 03-3980. San Antonio TX: Southwest Research Institute, 1975.

APPENDIX A

TORSION CELL MODELING

The T-38 horizontal stabilizer is being modeled with plate and bar elements. These elements do not simulate the torsion stiffness of the cell structure formed by the stabilizer's skin. To find the parameters and their magnitudes required to simulate the torsion cell stiffness a simplified modeling problem was investigated. A thin plate was chosen to model the stiffness of a thin hollow rectangular section in torsion. The angular displacements per unit torque were equated and the magnitudes of each parameter calculated.

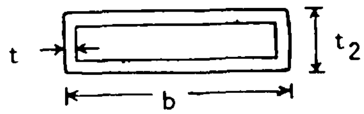
Plate



$t_1 \ll b$

$$\theta = \frac{3T}{b t_1^3 G_1}$$

Hollow Section



$t_2 \ll b$

$$\theta = \frac{T}{4A^2 G} \oint \frac{ds}{t} = \frac{T\, 2(b+t_2)}{4(t_2 b)^2 G t}$$

$$\frac{b+t_2}{b} \cong 1$$

$$\theta = \frac{T}{2 b t_2^2 t G_2}$$

Equating $\frac{\theta}{T}$

$$6 t_2^2 t G_2 = t_1^3 G_1$$

if $t = t_2$ then

G_1 would need to be 6 times G_2

or t_1 needs to be 1.82 times t

more realistic might be $4t = t_2$

G_1 would need to be 96 times G_2

or t_1 would need to be 4.58 times t

APPENDIX B

CHANGES IN THE MODEL'S FREQUENCIES, MODAL MASSES, MODAL STIFFNESSES AND ERROR FUNCTION WITH CHANGES IN THE PARAMETERS

PARAMETER	MODE	FREQUENCY	MODAL MASS	MODAL STIFFNESS	% FREQUENCY ERROR	ERROR FUNCTION
	1	47.85	.0117	1055	----	
Untuned	2	79.77	.0069	1745	20.23	
Model	3	89.74	.0027	866	27.63	44.00
	4	115.80	.0044	2335	27.63	
E	1	48.88	.0123	1158	----	
Increased	2	82.81	.0067	1802	17.19	
10%	3	92.57	.0031	1037	25.35	39.84
	4	119.24	.0048	2716	25.48	
E	1	50.25	.0130	1300	----	
Increased	2	86.51	.0065	1916	13.49	
25%	3	95.74	.0034	1235	22.79	34.16
	4	125.47	.0074	4590	21.58	
E	1	50.67	.0133	1346	----	
Increased	2	87.69	.0064	1953	12.31	
30%	3	96.73	.0035	1307	21.99	32.76
	4	126.51	.0211	3745	20.93	
E	1	51.48	.0137	1436	----	
Increased	2	89.99	.0063	2025	10.01	
40%	3	98.64	.0038	1462	20.45	29.94
	4	128.90	.0053	3470	19.44	
E	1	52.23	.0142	1525	----	
Increased	2	92.20	.0062	2094	7.80	
50%	3	100.46	.0041	1635	18.98	27.23
	4	131.36	.0053	3635	17.90	
G	1	48.83	.0114	1069	----	
Increased	2	81.22	.0070	1812	18.78	
10%	3	91.85	.0027	890	25.93	41.70
	4	117.27	.0045	2457	26.71	
G	1	49.71	.0110	1077	----	
Increased	2	82.19	.0071	1901	17.81	
20%	3	93.32	.0025	868	24.74	40.10
	4	118.3	.0047	2618	26.06	
G	1	50.51	.0108	1084	----	
Increased	2	83.12	.0073	1990	16.88	
30%	3	94.71	.0024	851	23.62	38.59
	4	119.33	.0050	2788	25.42	
G	1	51.25	.0105	1090	----	
Increased	2	84.03	.0075	2078	15.97	
40%	3	96.03	.0023	837	22.56	37.15
	4	120.29	.0052	2976	24.82	

PARAMETER	MODE	FREQUENCY	MODAL MASS	MODAL STIFFNESS	% FREQUENCY ERROR	ERROR FUNCTION
G	1	51.92	.0103	1095	----	
Increased	2	84.90	.0076	2166	15.10	
50%	3	97.27	.0022	825	21.56	35.78
	4	121.21	.0055	3201	24.24	
Density	1	49.61	.0108	1048	----	
Decreased	2	82.40	.0064	1709	17.60	
10%	3	92.84	.0028	962	25.13	39.70
	4	119.68	.0037	21.01	25.20	
Density	1	51.60	.0098	1035	----	
Decreased	2	84.74	.0060	1693	15.26	
20%	3	95.70	.0028	1020	22.82	35.72
	4	123.44	.0032	1938	22.85	
Density	1	53.91	.0089	1020	----	
Decreased	2	87.35	.0055	1666	12.65	
30%	3	99.04	.0028	1095	20.13	31.27
	4	127.50	.0028	1819	20.31	
Density	1	56.54	.0080	1004	----	
Decreased	2	90.08	.0052	1651	9.92	
40%	3	102.7	.0028	1187	17.18	26.58
	4	131.7	.0025	1739	17.69	
Density	1	59.65	.0070	986	----	
Decreased	2	93.03	.0048	1625	6.97	
50%	3	107.01	.0029	1303	13.70	21.39
	4	136.20	.0023	1698	14.88	
Iyy	1	48.23	.0117	1071	----	
Increased	2	80.23	.0068	1724	19.77	
10%	3	90.50	.0028	911	27.02	43.13
	4	116.50	.0042	2233	27.19	
Iyy	1	48.60	.0116	1078	----	
Increased	2	79.80	.0069	1746	20.20	
20%	3	90.14	.0027	858	27.31	43.52
	4	116.47	.0041	2213	27.21	
Iyy	1	48.96	.0115	1089	----	
Increased	2	79.81	.0069	1747	20.19	
30%	3	90.32	.0027	855	27.16	43.31
	4	116.76	.0040	2163	27.03	
Iyy	1	49.32	.0115	1106	----	
Increased	2	80.26	.0068	1728	19.74	
40%	3	91.07	.0027	898	26.56	42.50
	4	117.34	.0038	2088	26.66	

PARAMETER	MODE	FREQUENCY	MODAL MASS	MODAL STIFFNESS	% FREQUENCY ERROR	ERROR FUNCTION
Iyy	1	49.65	.0114	1112	----	
Increased	2	79.83	.0069	1747	20.17	
50%	3	90.65	.0026	849	26.90	42.74
	4	117.26	.0038	2083	26.71	
I	1	47.86	.0117	1062	----	
Increased	2	80.23	.0068	1722	19.77	
10%	3	90.29	.0029	918	27.19	43.36
	4	116.18	.0043	2298	27.39	
I	1	47.87	.0117	1063	----	
Increased	2	80.25	.0068	1721	19.75	
20%	3	90.29	.0029	919	27.19	43.35
	116.20	.0043	2299	27.38		
I	1	47.87	.0118	1065	----	
Increased	2	80.27	.0068	1721	19.73	
30%	3	90.30	.0029	919	27.18	43.32
	4	116.22	.0043	2300	27.36	
I	1	47.86	.0117	1061	----	
Increased	2	79.84	.0069	1742	20.16	
40%	3	89.76	.0027	869	27.61	43.92
	4	115.88	.0044	2338	27.58	
I	1	47.86	.0118	1063	----	
Increased	2	79.86	.0069	1741	20.14	
50%	3	89.77	.0027	869	27.60	43.90
	4	115.90	.0044	2339	27.56	
Airfoil	1	52.48	.0120	1302	----	
Thickness	2	86.93	.0072	2156	13.07	
Increased	3	98.59	.0028	1060	20.49	32.14
10%	4	126.36	.0051	3233	21.03	
Airfoil	1	59.21	.0126	1738	----	
Thickness	2	97.34	.0077	2876	2.66	
Increased	3	111.35	.0029	1400	10.20	16.47
25%	4	139.75	.0054	4146	12.66	
Airfoil	1	61.38	.0128	1900	----	
Thickness	2	100.69	.0078	3131	-.69	
Increased	3	115.41	.0029	1521	6.93	12.19
30%	4	143.99	.0056	4601	10.01	
Airfoil	1	63.79	.0130	2086	----	
Thickness	2	104.93	.0077	3337	-4.93	
Increased	3	119.09	.0030	1670	3.96	10.01
34%	4	147.59	.0058	5017	7.76	

PARAMETER	MODE	FREQUENCY	MODAL MASS	MODAL STIFFNESS	%FREQUENCY ERROR	ERROR FUNCTION
Airfoil	1	64.46	.0131	2151	----	
Thickness	2	105.49	.0080	3502	15.49	
Increased	3	120.97	.0033	1882	2.44	8.76
37%	4	149.81	.0060	5293	6.37	
Airfoil	1	65.65	.0126	2257	----	
Thickness	2	107.28	.0081	3668	-7.28	
Increased	3	123.51	.0032	1940	.40	8.79
40%	4	152.15	.0061	5602	4.91	
Airfoil	1	66.88	.0134	2370	----	
Thickness	2	109.14	.0082	3848	-9.14	
Increased	3	125.92	.0031	1918	-1.55	9.88
43%	4	154.53	.0063	5931	3.42	

NOTE:

Mode 1 = 1st Bending
Mode 2 = 1st Torsion
Mode 3 = 2nd Bending
Mode 4 = 2nd Torsion

Parameters changed in elements listed in text.

VITA

Lex Clayton Dodge was born on 23 March 1955 in Seattle, Washington. He graduated from El Camino Real High School, Woodland Hills, California in 1973 and attended the Air Force Academy from which he received the degree of Bachelor of Engineering Mechanics in June 1977. Upon graduation, he received a commission in the United States Air Force and was assigned to the Technical Development Branch, 6510 Test Wing, Edwards AFB as a Mechanical Engineer. In 1978 he was transferred to the Structures Group and served as an Aircraft Structures Flight Test Engineer until entering the School of Engineering, Air Force Institute of Technology in June 1980.

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Stabilizer
Mode Shape
Flutter Analysis

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This thesis investigates tuning a finite element model and applying the procedures to the T-38 horizontal stabilizer for use on NASTRAN. The T-38 stabilizer model is to be used in a subsequent flutter analysis.

Static and dynamic analysis has shown the model to have inadequate bending and torsional stiffness. The model was tuned in the frequency domain with free-free boundary conditions. The tuned frequencies and mode shapes show good correlation to the measured values. The finite

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) element model was shown to not contain variables that significantly influence the torsion modes frequencies more than the bending frequencies.

Eigenvalue analysis of the tuned model with aircraft installed boundary conditions produced good results for all but the first torsion frequency. This frequency was tuned by increasing the model's control system stiffness. This tuned model produces good frequencies and mode shapes. Additional investigation is needed to compare the dynamic model corrections to the static model corrections found by Jack Sawdy, AFIT/GAE/AA/81D-27.

DA

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